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Report to the Australian Research Council

A Wealth of Knowledge

The return on investment from ARC-funded research

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Executive Summary

Summary of key findings

The two key findings from this study, based on both a 'bottom up' and 'top down' analysis, are that:

1. **returns on investment in ARC-funded research are high in absolute terms; and**
2. **returns on investment in ARC-funded research are high relative to the average returns associated with all publicly funded research.**

ARC research funding in the year 2003 alone is estimated to produce significant net benefits for the Australian economy over the period to 2018. While funding the ARC in 2003 was equivalent to an $18 contribution from each person in Australia, the returns generated from the ARC's activities are forecast to be the equivalent of consumption being $14 per capita higher in 2003 than it would have been if this contribution to the ARC had not been made. This return is the net present value of real consumption per capita over the 2003-2018 period above that which would have been enjoyed had the ARC not been funded in 2003, i.e. the $18 investment has been recouped and an additional $14 in real consumption per capita generated. This represents a much higher return than could be generated through government securities. These returns are based on our conservative 'bottom up' approach to the measurement of returns on ARC funding.

The 'bottom up' analysis of benefits from ARC research funding conducted in this report identified a measurable total social rate of return on ARC investment in Australia of 39 per cent. The social rate of return is defined as the permanent increase in GDP as a percentage of the dollar cost of the investment that led to this increase. It must be stressed that this estimate of returns relating to ARC-funded R&D does not fully capture all possible sources of benefit. Health, environmental, social and cultural benefits for instance have not been quantified in this study.

This measured rate of return is strong, not only in absolute terms but also when compared to the average social rate of return on all publicly funded R&D. The 'top down' analysis of sources of economic growth conducted in this study suggested that the social rate of return on ARC-funded research is 50 per cent, compared to an average rate of return of all publicly funded R&D of 25 per cent.

That the measurement of benefits conducted through the 'bottom up' analysis, which does not fully capture all possible sources of benefit, showed a rate of return of 39 per cent suggests that the 50 per cent figure from the 'top down' analysis is in fact highly plausible and that ARC funding does in fact generate significantly higher returns than is the average for all publicly funded R&D.

Context for this study

The Australian Research Council (ARC) primarily provides funding for basic research and research capability in the Universities and for linking such research to end users. This funding should properly be seen as an investment by the Commonwealth Government for the purpose of generating benefits to Australia.

The ARC commissioned this report to provide an estimate of the return on investment on ARC-funded research. This is a challenging task for a number of reasons:

- the channels by which benefits flow from ARC-funded research are numerous – there is a lot more to the generation of net benefits than the gains from the commercialisation of intellectual property created as a result of ARC-funded research;
- the benefits themselves are diverse – coming as they do in the form of economic, health, environmental, social and cultural benefits;
- often the lead time between the research itself and the reaping of benefits from the research can be significant – the 1999 White Paper acknowledged that "the return on investment from research is long term";
- the benefits that flow can be both direct and indirect; and
- generally, in the process of going from knowledge generation to markets or use, other complementary investments will have been made, which raise issues of attribution of benefits to particular funding sources.

While a considerable body of empirical work has been built up in many countries estimating the returns to R&D, this has tended to focus more on private sector R&D rather than on research supported by the public sector. We have therefore been required to break new ground in some important areas in seeking to provide answers to the questions posed by this study's objectives.

Large claims have sometimes been made about the net benefits associated with particular kinds of research – claims which have not necessarily stood up under closer investigation. In order to generate credible estimates of returns on ARC funding of research, in this study we have throughout adopted a conservative approach to identifying and measuring benefits.

The role of the ARC

In the knowledge-based economy a nation's innovative capacity or national innovation system is seen as vital to the process of future value creation and competitiveness in the 21st Century. The national innovation system comprises all the institutions, people, and processes that create, share and use new knowledge and most importantly the linkages and interactions between them. It includes government, higher education and business elements.

The ARC's mission is to "advance Australia's research excellence to be globally competitive and deliver benefits to the community". This means activities in three broad areas:

- supporting the best research which is most likely to contribute to innovation;
- brokering partnerships between researchers, industry, government, community organisations, and the international community; and
- providing policy advice to the Australian Government on investment in the national research effort.

In terms of generating social and economic benefits, the key features of the ARC's activities are its role in:

- developing and maintaining a broad foundation of high–quality world–class basic research across a wide range of disciplines, including facilitating access for Australian researchers to state–of–the–art facilities and equipment and providing incentives for the cooperative development of research infrastructure;
- contributing to the development and implementation of a coordinated approach to setting priorities in research and research training in order to maximise the benefits for Australia of such activity;
- encouraging and extending cooperative approaches to research by strengthening links within Australia's innovation system and with innovation systems internationally;
- contributing to high-quality research training and fostering the careers of Australia's best and brightest researchers; and
- communicating the outcomes of research to broad stakeholders.

Perhaps the most important feature of the ARC's activities is that funding is competitively allocated on the basis of research excellence. Available evidence suggests that ARC-funded research does in fact as a result produce output of higher impact than that of publicly funded research in general. For instance, papers in the biological sciences produced by ARC Centres and by ARC Grantees are respectively 4 and 3 times as likely to be in the top 1 per cent of cited papers as papers produced in universities where the researchers were not recipients of ARC funding (Grigg 1999).

The ARC's focus on excellence, building the research infrastructure base, directing resources to high-potential areas, building linkages to the broader national and international innovation system, supporting research training and communicating the results of research to stakeholders (including policy makers) each generate particular channels of benefits.

Categories of benefits from ARC research funding

Based on a review of relevant literature and a consideration of the particular role of the ARC within the Australian innovation system, we have identified six primary channels through which economic, health, environmental and social/cultural benefits from ARC research funding are realised. These benefit channels are:

- benefits from building the basic knowledge stock;
- benefits from generation of commercialisable intellectual property;
- benefits from improving the skills base;
- benefits from improving access to international research and international networks;
- benefits from better informed policy making; and
- health, environmental, social and cultural benefits.

In this study, benefits generated in each of these areas are identified and, where possible within the constraints of this study, quantified.

Two approaches to estimating benefits

In this study two approaches have been adopted to attempt to quantify the social and economic benefits associated with ARC-funded research activities in Australia.

The first approach, the 'top down' approach, involved a review of Australian and international studies on the relationship between funding for R&D and multi-factor productivity growth. This productivity analysis approach was not based on a specific analysis of observed impact of ARC research funding in Australia, but rather on analysis of the average observed impact of research funding on productivity growth in Australia and other developed economies. This 'top down' analysis provides a 'benchmark' estimate of the impacts of ARC research funding.

Through this 'top down' approach we identify:

- the key drivers of MFP growth;
- the contribution of all R&D to MFP growth;
- the relative contribution of public R&D to MFP growth within advanced economies; and
- through consideration of the characteristics of ARC funding activities, a theoretically justifiable estimate of the contribution of ARC research funding to Australian MFP growth during the 1990s.

The results of this analysis are then converted to an estimate of the dollar impact on GDP associated with ARC research funding during the 1990s. Once the contribution to GDP (measured in terms of the extent to which GDP is higher by the end of the 1990s than it would have been without ARC funding) made by ARC funding has been estimated it is then possible to compare this to the total value of ARC funding made during the 1990s. This gives us a 'ball-park' estimate of the social rate of return on ARC funding. The social rate of return is defined as the permanent increase in GDP as a percentage of the dollar cost of the investment that lead to this increase.

The second approach adopted, the 'bottom up' approach, involved a more complex analysis of the specific impact of ARC research funding in Australia. This approach involved examination of the level of benefits (in each of the six areas listed above) that can be traced to ARC research funding. Under each category of benefits, past and current ARC funding was examined and links between that funding and benefits generated considered. This 'bottom up' approach is highly specific to the Australian environment and yields results that are as accurate an assessment of the ARC research funding as could be obtained given the time constraints of this study.

Based on the findings from the 'top down' and 'bottom up' analysis, modelling scenarios were then developed to estimate the wider impacts of ARC research funding on the Australian economy.

Key findings

A 'top down' analysis of the role of ARC funding in economic growth was conducted in this study to provide a 'ball-park' estimate for returns on ARC funding. The review of the literature on technological progress and productivity growth suggests that technological change is responsible for around half of multi-factor productivity growth in advanced economies and that publicly funded R&D, such as that funded through the ARC, is an important contributor to technological progress in advanced economies such as Australia's.

Consideration of both the growth literature and the role of the ARC within the Australian innovation systems suggested that a 50 per cent social rate of return represents a reasonable estimate of the returns from ARC funding in Australia compared to an estimated average social rate of return on all publicly funded R&D in Australia of 25 per cent. This average rate of return figure for all publicly funded R&D of 25 per cent was arrived at through our 'top down' analysis of the sources of economic growth in Australia and a review of a number of Australian and international econometric studies.

There are a number of reasons why ARC funding could be expected to generate significantly higher returns over the longer term than the average returns for all public funding of R&D. These include that:

- ARC funding is allocated on the basis of research excellence by use of a competitive process, implying that the ARC is likely to fund only the best available research activities;
- ARC funding programs allow the ARC to respond to emerging high-potential fields of research more rapidly than occurs with public sector research funding directed to institutions;
- ARC research funding is more heavily focused on supporting 'breakthrough' research, which the international literature suggests has higher rates of spillover benefits than other forms of public R&D funding;
- the ARC tends to fund high-potential research at the early, riskiest stages of the innovation process. Therefore, even when other funding is later provided from sources such as Co-operative Research Centres and the R&D Start Grants program, it may be that the ARC funding is relatively more important in enabling the development of resulting intellectual property.;
- the ARC funds infrastructure and projects that assist in the training of a high number of postgraduate researchers suggesting that the ARC plays a relatively significant role in the generation of benefits from improving the skills base; and
- ARC funding allows leading-edge equipment to be purchased which is then available for use by researchers on other projects.

It must be stressed though that the results of the 'top down' analysis, because they are based on the average impacts of research funding in a number of developed economies, should be viewed as providing a plausible order of magnitude of the impact of ARC research funding rather than a precise figure based on detailed consideration of the links between ARC funding and associated benefits that have been observed in Australia. The generation of such Australian-specific results requires application of the 'bottom up' analysis that is detailed below.

Based on a conservative 'bottom up' analysis of benefits from ARC research funding, the total social rate of return on ARC investment in Australia is measured at 39 per cent. The social rate of return is defined as the permanent increase in GDP as a percentage of the dollar cost of the investment that lead to this increase. This estimated return is strong considering that the average social rate of return on publicly funded R&D appears to be around 25 per cent. It should however be noted that the estimate of returns relating to ARC-funded R&D is only a partial measure of overall benefits, as not all benefits (such as health, environmental, social and cultural benefits) have been able to be quantified in this study. The 'bottom up' estimate of returns also suggests that the 'top down' estimate of a 50 per cent social rate of return on ARC-funded R&D is highly plausible and that ARC funding does in fact generate higher returns than is the average for all publicly funded R&D.

Table ES1 sets out the measured returns from ARC research funding in each of the six key benefit areas identified in this study.

Table ES1

SUMMARY OF BENEFITS FROM ARC FUNDING OF RESEARCH

Category of Benefits	Measured Benefits
Benefits from building the basic knowledge stock	In this area an 10% social rate of return on average from ARC funding (clearly some ARC funding generates higher returns in this channel and other types of ARC funding generate lower returns through this channel) with a ten-year time lag was identified. This is based on the relative success of ARC-funded research finding a route to use and the high pay-offs achieved when this occurs.
Benefits from generation of commercialisable intellectual property	In this area an average 3% social rate of return from ARC funding with a ten-year time lag was identified. This estimate is based on observed impacts from commercialisation of ARC-funded research over the past 25 years.
Direct benefits from improving the skills base	In this area an average 12.5% social rate of return from ARC funding with a four-year time lag was identified. This estimate is based on observed output impacts from the skills formation to which the ARC contributes.
Benefits from improved access to international research	In this area an average 7.5% social rate of return from ARC funding with an eight-year time lag was identified. This estimate is based on the level of access to international research funding that the ARC enables Australia to gain and the returns we obtain from this international research.
Benefits from better informed policy making	In this area an average 6% social rate of return from ARC funding with an eight-year time lag was identified. This estimate is based only on the observed impacts associated with microeconomic reform in Australia and the assumption that the ARC contributed only 0.25 per cent to microeconomic reform policy.
Health, environmental and cultural benefits	While the benefits in this area are likely to be significant, it has not been possible within the time constraints of this study to estimate returns in monetary terms.

Source: Chapters 4 and 6 of this study discuss each of these benefit channels in detail.

It is important to note that the returns outlined above accrue with time lags ranging from four to ten years.

The above findings provided the basis for subsequent modelling of the expected economic impacts from ARC funding in 2003. The modelling indicated that, due to ARC funding in 2003 alone, real GDP (plus $216 million) and real investment (plus $50 million) would be expected to be higher in 2018 than they would have been in the absence of ARC funding in 2003. The modelling fully factored in the time lags associated with the commencement of different benefit flows.

The impact on real consumption, a good proxy for overall economic welfare, from ARC funding in 2003 is that real consumption in 2018 is $166 million (2003 dollars) higher than it would have been without that funding being made. The Net Present Value (in 2003 terms) of the cumulative impacts on real consumption over the period 2003-2018 is $268 million (this net present value figure is based on a 5 per cent real annual discount rate being applied to impacts in future years). This represents a very strong level of return on the ARC's investment of approximately $350 million in 2003.

Given that some of the knowledge and skills generated through 2003 funding will be approaching the end of their useful life after 2018, the above figure represents the bulk of the measurable benefits that will be attributable to the ARC funding made in 2003.

The level of benefits generated by the 'bottom up' analysis (based on a measured total social rate of return of 39 per cent) are slightly lower than those predicated by the theoretical 'top down' approach to measuring benefits from ARC research funding (which suggested a social rate of return on ARC funding of around 50 per cent). This is not a surprising result.

Unlike the theoretical analysis, our observation-based approach factors in only those benefits that could be reasonably identified and quantified and factors in the time lags associated with these benefit flows. Our 'bottom up' analysis does not include quantification of several important potential areas of benefits such as health, environmental, social and cultural benefits. It is also likely, given the richness of the potential menu of benefit channels, that we have not fully identified all the benefits that have accrued in relation to the use and commercialisation of basic knowledge. Benefits in these areas have been based only on a limited set of examples.

Due to the partial nature of the measurement of benefits and the fact that throughout this report we have used conservative assumptions in measuring returns on ARC funding, the measured social rate of return should be seen as being as approximating a 'lower bound' estimate of returns.

Notwithstanding the conservative nature of our estimates, ARC funding in the year 2003 alone is estimated to produce significant net benefits for the Australian economy over the period to 2018. While funding the ARC in 2003 was equivalent to an $18 contribution from each person in Australia, the returns generated from the ARC's activities are equivalent to consumption being $14 per capita higher in 2003 than it would have been if this contribution to the ARC had not been made. This return is the net present value of real consumption per capita over the 2003-2018 period above that which would have been enjoyed had the ARC not been funded in 2003, i.e. the $18 investment has been recouped and an additional $14 in real consumption per capita generated.

Another factor impacting on the level of returns projected for ARC funding is that estimates of future benefits are based on past observed rates of return. There is reason to believe that returns from ARC funding, particularly in the use and commercialisation of basic knowledge, may in fact be significantly higher in the future than they have been in the past. This is a consequence of factors both within the modus operandi of the ARC itself and external to the ARC which suggest that the economic impacts from ARC activity may be relatively greater in the future than they have been over the past decade. The three factors we have in mind are:

- improvements in the future positioning of the ARC;

- improvements in a number of complementary elements of the Australian innovation system which influence “routes to use” and “routes to market”;
- the likelihood of the emergence of new, breakthrough areas of research which will spur the development of new high-technology industries.

In regard to the potential for commercialisation of ARC-funded research in the future, an independent working group supported by the Prime Minister’s Science, Engineering and Innovation Council secretariat has noted that commercialisation of public sector research is on the rise in Australia. However, the working group believes there may currently be many missed opportunities that could deliver economic returns. Highlighting the scale of potential benefits that improved commercialisation performance could bring, the working group proposed:

> “If we can grow 200 – 250 more Australian research-based companies like five of those shown in this report over the next five years, the prize would be around $20 billion added to our annual export earnings.”
>
> PMSEIC (2001), *Commercialisation of Public Sector Research*, Paper for seventh meeting, 28 June 2001

Given the significant economic returns on ARC funding in the past and the strong prospects for even higher future returns on ARC funding, the continued activities of the ARC are likely to make a substantial contribution to higher Australian standards of living in the future.

Section One

Introduction

1.1 Report context

Since the groundbreaking work of Robert Solow[1] in developing a modern theory of economic growth that recognised the importance of technological innovation and the underlying knowledge base, a growing body of economic analysis has suggested that there is a strong correlation at the aggregate level between the rate of growth in a country's investment in R&D and its rate of growth in GDP[2].

The transition of the more advanced countries to knowledge-based economies and societies has increased awareness of the importance of their national innovation systems to economic growth. Basic research, which is primarily carried out in the universities, is now seen as an increasingly important element of the national innovation system – the researchers not only contribute ideas that can directly create economic potential but they also play important roles in knowledge and technology diffusion in the community. In Australia the Australian Research Council (ARC) is a major source of funding for basic research and the researchers who undertake it.

The research funded by the ARC should properly be seen as an investment that is being made by the Commonwealth with the purpose of generating benefits to Australia and contributing to the world's stock of knowledge – from which all countries, including Australia, draw. As with any investment, it is important to measure as far as possible the returns associated with the investment in R&D that the Commonwealth makes through the ARC. Unless returns are estimated, it will be hard for the Government to rationally determine appropriate future levels of funding for the ARC. It is therefore necessary to seek to determine the return that is associated with the investment in ARC-funded research if the Government is to make well informed decisions in relation to future funding of the activities of the ARC.

1.2 Challenges in measuring returns on R&D funding

There are a number of pathways by which investment in research produces a rate of return to the Commonwealth and to the community. The fundamental purpose of the ARC in supporting excellent research is to contribute to the creation of knowledge. The knowledge so created can have a number of benefits which contribute to the community's economic, social/cultural and environmental objectives (the so-called triple bottom line).

Economic benefits can come in a number of ways[3]:

- the direct application of research findings;
- the generation of intellectual property which is valuable in its own right;

[1] In 1987 Solow received the Nobel Prize for Economics for his pioneering work in the 1950s in developing a new theory of economic development.

[2] The linkage between R&D and productivity growth is considered in detail in section five.

[3] The report (1998) by Prof. John Stocker and Don Mercer, *Review of Greater Commercialisation and Self-Funding in the CRCs Programme*, provides some useful insights into the pathways by which research generates benefits for the economy and the community.

- the creation of spin-off businesses which provide high-value jobs and wealth;
- the output of trained researchers who become part of the nation's scientific and research capability and who play important roles in knowledge and technology diffusion to the community;
- through funding participation in international research projects and hence gaining early access to overseas research findings;
- helping to keep leading academics in Australia, thus improving the quality of the Australian innovation system; and
- through development of new products and processes increasing the productivity within particular industries.

There is also a range of social/cultural and environmental benefits associated with research funded by ARC grants which are by their nature much harder to value in purely monetary terms but which are nevertheless valued by the community.

Further complicating this study is the heterogeneity of research funded by the ARC, in terms of: the subject matters covered – the ARC funds research in virtually all fields except clinical medicine and clinical dentistry: the nature of the grants provided, which are now roughly 60 per cent for Discovery (investigator-initiated research) grants and 40 per cent for Linkage grants (in which there is frequently an industry partner involved); and the support provided for ARC Centres in addition to individual research projects. While this particular structure was introduced relatively recently, over the last decade ARC funds have consistently supported research, research cooperation, research training and research links with industry.

Representing as it does an investment, research funded by the ARC can be expected to have a considerable gestation period. The research stage itself can run in excess of 5 years while the period it takes for a clear benefit to be observed could be as much as a further 10 to 15 years. It is therefore necessary to look back at the funding made by the ARC and its predecessor organisation over a considerable time period.

A final important challenge is to disentangle the benefits that are primarily associated with research funded by the ARC and those whose origins owe more to investments made by other parties.

1.3 Report structure

This report has been structured into eight sections. These are:

- *Section One*: an outline of the context for the report, key challenges in measuring returns on ARC research funding, description of report methodology and outline of report structure.
- *Section Two*: contains an overview of the role and activities of the ARC and the drivers of ARC decision-making processes.
- *Section Three*: Sets out the key categories of benefits associated with ARC research funding.
- *Section Four*: outlines 'top down' and 'bottom up' approaches to quantifying outcomes from ARC-funded research.

- *Section Five*: outlines findings from the 'top down' approach to quantifying outcomes from ARC-funded research.
- *Section Six*: outlines findings from the 'bottom up' approach to quantifying outcomes from ARC-funded research.
- *Section Seven*: sets out the modelling scenario and analyses the key results from the scenario modelling.
- *Section Eight*: overall conclusions relating to the return on investment on ARC research funding are set out and future prospects explored.
- *Appendix One*: contains a number of detailed case studies of ARC-funded research projects.
- *Appendix Two*: contains the detailed modelling report from the Centre of Policy Studies.
- *Appendix Three*: lists references.

Section Two

The role, functions and investment strategy of the ARC

This chapter sets out the role, functions and investment strategies of the ARC. It also delineates the position of the ARC within the national innovation system and the nature of its relationship to other Government R&D programs such as the CRC program. The ARC's mission, the kinds of research it supports and its linkages to the rest of the national innovation system all have implications for the nature and scale of benefits that are likely to be generated through ARC research funding.

2.1 The role and functions of the ARC

The ARC's mission is to "advance Australia's research excellence to be globally competitive and deliver benefits to the community". This means activities in three broad areas:

- supporting the highest-quality research and research training through national competition in all fields of science, social sciences and the humanities;
- brokering partnerships between researchers and industry, government, community organisations and the international community; and
- providing policy advice to the Australian Government on investment in the national research effort.

The ARC provides grants to support high-quality research by individuals or teams in all research areas, except clinical medicine and clinical dentistry research which is the responsibility of the National Health & Medical Research Council (NHMRC).

The ARC was established in 1988 as the successor to the Australian Research Grants Committee (ARGC). The rationale underlying the ARC's establishment was to:

- consolidate the many funding sources in operation at the time and provide greater scale and flexibility in research grants; and
- achieve a coordinated approach to grants across a range of areas such as infrastructure, research, and career development opportunities.

From 1 July 2001, the ARC became an independent agency, governed by the *Australian Research Council Act 2001*. The ARC funds research and researchers under the National Competitive Grants Program (NCGP).

The programs are grouped into Discovery and Linkage. Discovery and Linkage replace earlier programs under NCGP, including Large Research Grants, Fellowships, Indigenous Researchers Development Scheme, Strategic Partnerships with Industry – Research and Training, Research Infrastructure Equipment and Facilities, International Researcher Exchange and International Research Fellowships, Special Research Centres and Key Centres of Teaching and Research.

Funding

Table 2.1 shows ARC funding from 1996 to 2002 measured in terms of 2000 constant dollar values. No growth in funding occurred between 1998 and 2002. Following the Commonwealth Government's decision based on the recommendation of the Wills Report to double funding for the NHMRC over five years the unusual situation emerged in which funding for the NHMRC was scheduled to exceed funding for the ARC if no increase in ARC funding was forthcoming.

Table 2.1

COMPETITIVE RESEARCH GRANTS AND INFRASTRUCTURE PROGRAMS ADMINISTERED BY THE ARC ($MILLION, CONSTANT 2000 VALUE)

1996 ($m)	1997 ($m)	1998 ($m)	1999 ($m)	2000 ($m)	2001 ($m)	2002 ($m)
199.6	216.5	238.5	231.1	240.7	239.2	238.7

Source: Chief Scientist (2000), *A Chance to Change*

Following the review of Australia's science capability by the Chief Scientist and his report *The Chance to Change* which recommended the doubling of ARC funding over five years, the Commonwealth Government announced its intention to do this in the Prime Minister's statement *Backing Australia's Ability*. Table 2.2 sets out the annual cap on ARC funding (in actual dollar values) between 2001 and 2006 showing expected growth in line with the Government's commitment on ARC funding.

The increasing monies available to the ARC reflect the increased government commitment, and a slight increase in the relative share of total government spend allocated to the ARC.

Table 2.2

EXPECTED ARC FUNDING

2001 ($m)	2002 ($m)	2003 ($m)	2004 ($m)	2005 ($m)	200 6($m)
247.83	272.42	356.06	403.60	461.05	524.09

Source: *Australian Research Council Act 2001*, s49

Table 2.3 shows the distribution of global funding between the individual program areas. It underlines the predominance of the discovery projects and research fellowships, representing in the order of 60 per cent of total ARC program funding. Given increasing ARC funding over time, this particular program is also growing strongly.

Table 2.3

ARC PROGRAM AND OPERATING BUDGETS, 2003 TO 2005

Program Area	2003 ($m)	2004 ($m)	2005($m)
Discovery — Projects (includes Research Fellowships)	183.595	200.124	211.931
Discovery — Indigenous Researchers Development	0.235	0.235	0.235
Federation Fellowships	15.698	23.494	31.290
Total Discovery	**205.528**	**223.853**	**243.456**
Linkage — Projects	71.252	90.497	108.776
Linkage — Infrastructure Equipment and Facilities	13.734	25.794	25.794
Linkage — International	3.171	3.143	3.016
Centres of Excellence	50.595	59.182	78.873
Linkage — Learned Academies Special Projects	0.472	0.472	0.472
Linkage — Special Research Initiatives	2.825	0.275	0.275
Linkage — Australian Postdoctoral Fellowships (CSIRO)	0.358	0.358	0.358
Linkage — ANZCCART	0.030	0.030	0.030
Yet to be allocated	8.098		
Total Linkage	**150.535**	**179.751**	**217.594**
Total Budget for ARC Programs	***356.063***	***403.604***	***461.050***
ARC Operations*	12.660	12.216	12.334

*Based on financial year ending June 30th of listed year

Source: *ARC Strategic Action Plan 2003–2005*

NB: 2004 and 2005 figures are forward estimates. Amounts in 2003 price levels (as at Feb 2003)

2.2 ARC Programs and Sub–Programs

Table 2.4 sets out the elements, sub-programs and sub-program aims and description for ARC Programs shown in the ARC Annual Report 2001-2002.

Table 2.4

PROGRAMS OF THE AUSTRALIAN RESEARCH COUNCIL

ELEMENT	SUB–PROGRAM	SUB–PROGRAM AIM AND DESCRIPTION
Discovery	Discovery–Projects (including fellowships)	Opportunities for a continuum of activities, from smaller projects to clusters of larger projects, to meet varied needs of researchers. Fellowships are awarded in four categories: Australian Postdoctoral Fellowships (APDF), Australian Research Fellowships (ARF), Queen Elizabeth II (QEII) Fellowships, and Australian Professorial Fellowships (APF).
	Federation Fellowships	Aim to attract and retain leading Australian researchers in key positions that lead to lasting Australian benefits. Up to 25 fellowships to be awarded per year for five years commencing 2002. Each to have a five–year tenure with salary of approximately $230,000 per year (plus on–costs). Hosts for the Fellows are expected to match the Commonwealth financial commitment.
	Discovery–Indigenous Researchers Development	Aims to develop the research expertise of Indigenous Australian researchers to a level that is competitive with other researchers applying for mainstream research funding. This includes support for training in research methodology and preparation of research applications.
Linkage	Linkage–projects (including fellowships and postgraduate awards)	Collaborative research projects between higher education researchers and industry.
	Centres	This includes *Special Research Centres* and *Key Centres of Teaching and Research* which were designed to promote excellence in teaching and research activities in higher education institutions. They are being progressively replaced by ARC Centres of Excellence, and joint centres co-funded with other bodies.
	Linkage–Infrastructure Equipment and Facilities	Encourages collaboration between institutions across the higher education sector as a whole, as well as between the sector and outside organisations.
	Linkage–International	Funding to support the movement of researchers between Australian research institutions and centres of research excellence overseas. Funding is provided in the form of both fellowships and awards.
	Linkage–Learned Academies Special Projects	Fosters linkage between government and research communities. Funding is provided on a competitive basis to support special projects expected to be broadly beneficial to Australian research communities.
	Special Research Initiatives	Designed to encourage greater collaboration among Australian researchers.

Source: ARC Annual Report 2001–2002, Appendix 1, pp136–138

Further programs have been implemented in 2003 under the *Linkage* element, including:

- a new postdoctoral fellowship program, Linkage–Australian Postdoctoral Award (CSIRO), jointly funded by the ARC and the CSIRO; and
- ARC Centres of Excellence; approximately $80 million over five years has been allocated for eight Centres of Excellence in the ARC research priority areas. These Centres will ensure focussed implementation of the ARC research prioirties and are designed to enhance the scale and focus of Australian research. These are in addition to the Biotechnology (National Stem Cell Centre), Information and Communications Technology (National ICT Australia) Centres of Excellence and the Australian Centre for Plant Functional Genomics.

2.3 Success Rates for Discovery-Projects

An important dimension to the ARC's activities is the allocation of Discovery-Projects. These grants have a maximum duration of five years and a maximum value of $500,000 per year, and provide for both the development of individual researchers' projects and the development of collaborative teams in basic research. Table 2.5 shows the distribution of funds and success rates for Discovery-Projects in 2002 across the six discipline clusters.

Table 2.5

NUMBERS AND SUCCESS RATES FOR DISCOVERY — PROJECTS BY DISCIPLINE CLUSTER 2002

Discipline Cluster	Applications Received	Withdrawn Applications	Successful Applications	Success Rate	Requested Funds 2003–2007 $	Recommended Funds 2003–2007 $
Biological Sciences and Biotechnology	659	10	167	25.7%	264,580,785	47,597,785
Engineering and Environmental Sciences	488	3	119	24.5%	180,297,296	33,198,700
Humanities and Creative Arts	576	4	145	25.3%	145,029,387	28,180,589
Mathematics, Information and Communication Sciences	482	3	137	28.6%	172,089,889	32,462,862
Physical, Chemistry and Geoscience	676	3	183	27.2%	293,271,317	58,508,697
Social, Behavioural and Economic Sciences	720	4	170	23.7%	183,490,037	31,229,200
TOTAL	**3601**	**27**	**921**	**25.8%**	**1,238,758,711**	**231,177,833**

Source: ARC, *Discovery*, December 2002

In 2002 the ARC considered 3601 applications under Discovery-Projects, requesting financial assistance of over $1.2 billion for the life of the proposed projects. There were 921 successful applications which represents a success rate, once withdrawn applications are taken into account, of 25.8 per cent. The successful applications involve an ARC funding commitment of $231.2 million over the period from 2003-2007, with $75.5 million being committed in 2003. Average first-year funding per project is $81,946 compared to $70,629 in 2002.

2.4 The ARC's approach to supporting research

In order to carry out its mission, "advance Australia's research excellence to be globally competitive and deliver benefits to the community", the ARC has constituted Expert Advisory Committees in six research areas. They are:

- Biological Sciences and Biotechnology;
- Engineering and Environmental Sciences;
- Humanities & Creative Arts;
- Mathematics, Information & Communication Sciences;
- Physics, Chemistry & Geoscience; and
- Social, Behavioural & Economic Sciences.

The *Australian Research Council Act 2001* sets out broad functions for the ARC, but provides significant flexibility around the precise manner of executing the functions. For example, while the Act requires the Board to establish funding rules, only broad guidance about the content of these rules is given.

The following key areas — set out in the *ARC Strategic Action Plan 2003–2005: Investing in our Future* — provide a guiding framework about the approach the ARC adopts in carrying out its broadly specified functions:

- *discovery* — to produce excellent research identified through peer review and open competition. The aim is to foster excellent research outcomes leading to innovation through providing flexible opportunities along a continuum from relatively small discrete research projects through to longer-term, team-based programs, research networks and centres of excellence;
- *linkage* — to promote research partnerships with business and industry and other publicly-funded research agencies, and connecting Australian researchers with the world's leading-edge knowledge, expertise and techniques in overseas business and research centres;
- *research training and careers* — to contribute to the excellence and international competitiveness of Australian research by fostering research training and career opportunities for Australia's best and brightest researchers;
- *research infrastructure* — to facilitate access for Australian researchers to world-class facilities and equipment, often via collaboration involving consortia of research organisations, including with overseas partners in the case of international facilities;
- *research priorities* — identification of priorities on the basis of excellence and national benefit to help ensure that positive outcomes from research are delivered to the community;
- *community awareness* — to develop and improve public understanding and appreciation of the contribution that research makes to the economic, social and cultural benefits of the community; and
- *governance* — to ensure the accountability and transparency of the ARC's operations and its overall effectiveness through appropriate governance, management and organisational structures and processes.

These objectives underline the holistic approach taken by the ARC.

The ARC has set out 34 Key Performance Indicators against which it monitors progress, and which are used to assess whether objectives are being achieved.

Essential features of the ARC approach include:

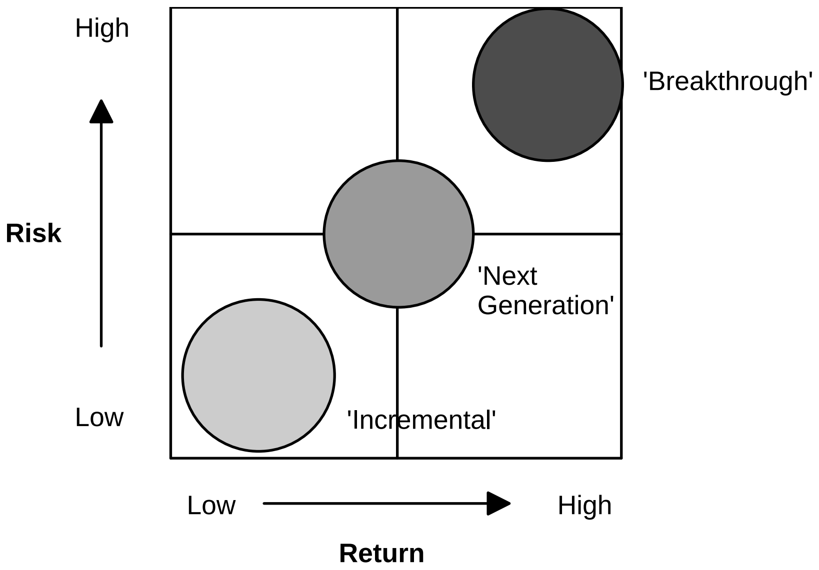
- use of competitive allocation mechanisms to support research excellence;
- accountability and peer review mechanisms to assist in the process; and
- (a relatively recent emphasis) communication of outcomes to broad stakeholders.

Investment strategy

In terms of the investment strategy of the ARC an important choice it faces is whether it invests in 'incremental', 'next generation' or 'breakthrough' research . The ARC sees itself as primarily investing in breakthrough research. Figure 2.1 provides a representation of the ARC activity within the 'risk–reward' spectrum. The ARC can be thought of as operating in the 'breakthrough' space in the upper right–hand quadrant, involving high risk and high-reward outcomes.

Figure 2.1

POSITIONING ARC-FUNDED RESEARCH WITHIN THE RISK–REWARD FRAMEWORK



Source: The Allen Consulting Group analysis

Other distinguishing features of the ARC's investment strategy include:

- A broadly 60:40 division between Discovery and Linkage grants. Over time the proportion of Linkage grants, whose aim is to bring about better linkages in the research system, has been tending to rise.
- A broadly 80:20 division between grants which support individuals and teams and those which support centres of excellence.
- An ability to respond to emerging areas of high research potential more quickly than other parts of the research system which tend to direct their primary effort to funding institutions.

2.5 The role of the ARC within the national innovation system

In the knowledge-based economy a nation's innovative capacity or national innovation system is seen as vital to the process of future value creation and competitiveness in the 21st Century. The national innovation system comprises all the institutions, people and processes that create, share and use new knowledge and most importantly the linkages and interactions between them. It includes government, higher education and business elements.

Furthermore, in the knowledge-based economy there is seen to be a close relationship between the research base and the ability to drive technological innovation in all its forms. A nation's basic research capability plays an important role in the generation of ideas which are the basis of future jobs growth and wealth creation as well as the quality of life.

A review is currently underway — under the auspices of the Commonwealth Department of Education, Science and Training (DEST) — entitled *Mapping Australia's Science and Innovation System*. It is being chaired by the Chief Scientist (Dr Robin Batterham) and will cover the following.

> The study will take stock of the state of Australian science, technology and innovation. It will cover key elements of the innovation process including Australia's ability to generate ideas and undertake science and related research and development; the commercial application and utilisation of research and the frameworks which support it; and the development and retention of relevant skills for science, innovation and enterprise.
>
> http://www.dest.gov.au/mapping/ accessed March 2003

This review is intended to address the lack of detailed understanding about the various aspects of the innovation system, and will cover consultations across the public and private sectors, and all States and Territories. An interim report is due in mid 2003, with a final report to follow later in the year.

While the results of the Science and Innovation Mapping exercise will be important to improving understanding of the way the innovation system works and in identifying any significant gaps that need to be addressed, nevertheless, there are a number of things that can now be said about the role and importance of ARC-funded research within the national innovation system. Box 2.1 sets out a mapping of the main Commonwealth support measures for R&D.

Box 2.1

MAPPING THE COMMONWEALTH GOVERNMENT'S MAIN SUPPORT MEASURES FOR R&D

Business R&D	
125% R& D Tax Concessions	The main beneficiaries of the tax concession are medium and larger sized companies. The tax concession provides a subsidy of about 8 cents in the dollar.
R&D Start Grants	The main beneficiaries of the Program are small to medium sized companies. Project grants are more generous than the tax concession, eg. Core Start provides grants of up to 50 per cent of project costs for Australian companies with a turnover of less than $50 million.
Rural R&D Corporations (RDCs)	The RDCs are purchasers and managers of R&D on behalf of industry levy payers and the public interest. The Commonwealth Government provides matching grants for industry R&D levies up to 0.5 per cent of the gross value of production for the industry concerned.
Research Agencies	
CSIRO	Australia's largest government research agency with coverage of all areas of science and industrial research except clinical medicine and dentistry. The CSIRO is organised into about 20 divisions and has 6,500 staff. It participates in many CRCs.
AIMS	Research agency specialising in marine science.
ANSTO	Research agency specialising in nuclear science and technology.
DSTO	Research agency specialising in defence science and technology.
Collaboration/Critical Mass	
Cooperative Research Centres (CRCs)	Major program to support research collaboration and to build linkages between researchers and users. There are currently 62 CRCs across a broad range of fields. CRCs generally comprise universities and government research agencies as the core of their research capability.
Major National Research Facilities	Competitive grant scheme for supporting major national research facilities.
Foundation Elements	
ARC	Primary provider of competitive grants based on excellence for research and training — also supports Centres of Excellence.
NHMRC	Primary provider of competitive grants for health and medical research.
Institutional Grant Scheme	Three basic programs for providing support to universities for research and research training.
Research Infrastructure Block Grants	
Research Training Scheme	

Source: Allen Consulting Group analysis

Defining Characteristics of ARC-funded Research and its Contribution to the Innovation System

If consideration is limited purely to counting dollars invested, the role of ARC-funded research would be judged to be modest – the ARC is budgeted to spend $356 million in 2003 which represents around 7 per cent of total expenditure on R&D by the Commonwealth and State Governments of $4.5 billion and about 3.5 per cent of total R&D expenditure from all sources.

The actual dollars spent, however, only tell part of the story. Through its focus on 'excellence' the ARC–funded research programs play an important role in providing the foundation of knowledge generation and researcher training which are at the disposition of all the other elements of the national innovation system. The NHMRC plays a similar foundation role in the areas of clinical medicine and clinical dentistry research.

The ARC is a major element of the research funding system for the Universities which has the prime responsibility for supporting research excellence and by extension the nation's University researchers most likely to be operating at the cutting edge of knowledge generation. Such research is most likely to produce ideas which have the best chance of providing a platform for successful technological innovation.

The impact of ARC-funded research is further enhanced by the fact that it tends to be primarily directed at 'breakthrough' research characterised by high risk and high returns if successful. The returns to society from incremental and intermediate research which are the provinces of the other elements of the research system are likely to be lower risk but also likely to offer lower returns.

One of the consequences of the funding model used by the ARC is that it primarily funds projects rather than research institutions and it is therefore more readily able to direct resources to emerging areas of research with high potential.

The ARC through its operations also has adopted two further strategies for magnifying its impact on the innovation system more generally. The first of these is through supporting Centres of Excellence which ensure the application of the benefits of critical mass to the outcomes achieved by research investment. The second is through Linkage grants which better connect the researchers being supported by the ARC to businesses which will ultimately apply the knowledge generated by ARC-funded research.

For all these reasons it is clear that ARC-funded research plays a special role within the national innovation system and generates above-average returns to the community in economic, social and environmental dimensions. As we will demonstrate, the ARC plays a key role in the Australian Government's investment in the future prosperity and well-being of the Australian community.

Section Three

Identification of sources of benefits from ARC research funding

This section identifies and discusses the key channels by which benefits flow from ARC-funded research. The identification of the type of benefits flowing from ARC-funded research has been determined by reference to the role, mission and priorities of the ARC (set out in section two) and through review of the relevant literature (both in Australia and overseas) on the subject of benefits associated with public R&D. This section also considers the extent to which these benefits can be assessed quantitatively.

3.1 Issues in identifying the key channels by which benefits flow

The identification of the key channels by which benefits from ARC funding activity flow is guided by consideration of the nature of the ARC's activities and its role within the Australian innovation system.

A number of the objectives set out in the *ARC Strategic Action Plan 2003–2005: Investing in our Future* provide guidance in determining the key areas of benefits from ARC funding. In terms of generating social and economic benefits, the key features of the ARC's activities are its role in:

- developing and maintaining a broad foundation of high–quality world–class basic research across a wide range of disciplines, including facilitating access for Australian researchers to state–of–the–art facilities and equipment and providing incentives for the cooperative development of research infrastructure;
- contributing to the development and implementation of a coordinated approach to setting priorities in research and research training in order to maximise benefits for Australia of such activity;
- encouraging and extending cooperative approaches to research by strengthening links within Australia's innovation system and with innovation systems internationally;
- contributing to high-quality research training and fostering the careers of Australia's best and brightest researchers; and
- communicating the outcomes of research to broad stakeholders.

The ARC's focus on excellence, building the research infrastructure base, directing resources to high-potential areas, building linkages to the broader national and international innovation system, supporting research training and communicating the results of research to stakeholders (including policy makers) each generate particular channels of benefits:

- the focus on excellence and building the research infrastructure base generates returns via building the basic knowledge stock;

- directing resources to high-potential areas and building linkages to the broader national innovation system lead to returns from the generation of commercialisable intellectual property;
- supporting excellence in research training generates benefits through building the skills base;
- increasing linkages to the international innovation system generates benefits from giving Australia improved access to the outputs of international R&D efforts; and
- the dissemination of research findings helps to improve policy making by Government.

3.2 Key benefit channels

The ways in which the research funded by the ARC provides benefits to the Australian community and the economy are multi–layered and complex — there is no single dominant benefit channel. Before considering the ARC situation, it is valuable to look at two significant reports, one an Australian report and the other a UK report, which both provide guidance on the most important benefit channels associated with basic research/publicly funded research. The key conclusions from these studies are shown in Box 3.1.

Box 3.1

AUSTRALIAN AND UK VIEW OF BENEFIT CHANNELS

An Australian View

The economic role of basic research is not directly to generate commercial products, but rather to provide essential support for, and raise the return on, more applied R&D. This is a much more diffuse role, but also a critically important one in successful innovation. It occurs through:

- training researchers, many of whom will work for industry or government;
- creating a store of "background knowledge" which improves the effectiveness of technological search activities;
- enabling membership of "networks" yielding access to the large body of knowledge generated worldwide; and
- developing new research techniques and instrumentation.

Industry Commission (1995)
Research and Development
Overview, page 5

A UK View

Despite the methodological problems discussed above in estimating the economic returns to public investment in basic research, one can distinguish various types of contributions that publicly funded research makes to economic growth:

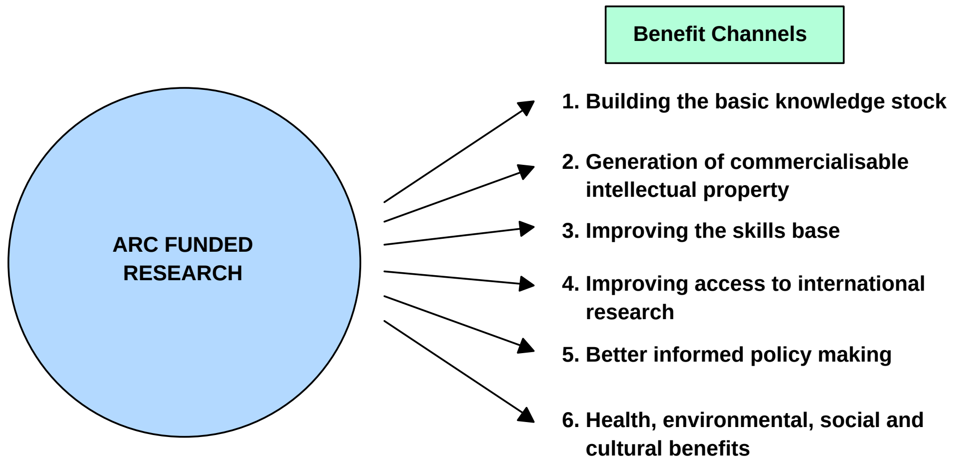
1) increasing the stock of useful knowledge;
2) training skilled graduates;
3) creating new scientific instrumentation and methodologies;
4) forming networks and stimulating social interaction;
5) increasing the capacity for scientific and technological problem solving;
6) creating new firms.

Salter, AJ & Martin, BR (1999)
Science Policy Research Unit
University of Sussex

Sources: Industry Com mission (1995) ; Salter, A., & Martin, B., (1999) Based on a review of relevant literature and a consideration of the particular role of the ARC within the Australian innovation system, we have identified six primary channels through which social and economic benefits from ARC research funding are realised. These benefit channels are shown in Figure 3.1 below.

Figure 3.1

ARC-FUNDED RESEARCH: KEY BENEFIT CHANNELS



Source: Allen Consulting Group analysis

The rationales for associating these benefit channels with ARC research funding are briefly discussed. Some preliminary discussion of the potential scale of such benefits is also included. Section 6 then considers our approach to measuring benefits in each of these areas and sets out the findings.

In addition to each of these specific benefit channels, for which in a number of cases the benefits are in principle quantifiable, investment in R&D acts at a very fundamental level to alter a country's ability to make economic, social and environmental progress. The core limiting constraint on a country's ability to advance in these areas is the ability of a country's population to embrace change itself. Through expanding knowledge and disseminating this knowledge to the community, investment in R&D can make a country's population more comfortable with change, and hence expand its ability to embrace new ways of acting. While it is not possible to measure this contribution from investment in R&D, and certainly not to isolate the impact of ARC funding in this area, the contribution R&D makes to national ability to embrace change may in fact be one of the most important returns on R&D investment.

Benefits from building the basic knowledge stock

A recent OECD investigation of the link between R&D and productivity growth[4] highlighted the role of research conducted within universities and public research institutions in building the basic knowledge stock. It suggests that, while new knowledge is not considered as a direct output in national accounts, it does play an important role in opening up opportunities for applied research that leads to new products and processes which in turn impact upon productivity. Basic knowledge can best be viewed as a fundamental building block of the innovation system.

[4] OECD (2001)

The link between basic knowledge and subsequent applied technological innovation was the focus of a major study by the US National Science Foundation in 1968. Its Technology in Retrospect and Critical Events in Science (TRACES) project used detailed case studies to trace the history of individual products or processes to their research origins. The TRACES project investigated the evolution of five major innovations and demonstrated the importance of the basic research knowledge base for each technological advance. It also indicated that the average time lag between the initial research and the translation of that research into applied innovations was ten years[5].

Given that the ARC has been operating in something like its present form only since 1989, the existence of a significant time lag between initial research and applied technological innovation, which has been estimated at between ten and twenty years in various studies[6], presents a methodological challenge in assessing the economic impact of ARC-funded research's contribution to the basic knowledge stock.

More recent empirical evidence for the role of basic knowledge in facilitating applied innovation was generated by a major study conducted by CHI research in 1997[7]. This study found that 73 per cent of the science papers cited by US industry patents were generated by publicly funded research. This study also found that the strength of the linkage between patented technologies and contemporary public science is growing. A similar study undertaken to investigate the link between Australian patenting and basic science[8] found that private sector patented technology is highly dependent on publicly funded science, with 90 per cent of papers cited in private sector Australian-invented US patents generated by publicly funded research institutions.

As the primary provider of competitive research grants for publicly funded research in Australia, the ARC plays an important role in the creation of valuable basic knowledge in Australia. This is not only due to its relative significance as a funder of basic research, but is also due to its particular role as a funder of 'excellent' basic research.

The importance of the ARC's focus on excellence is due to the fact that not all publicly funded research is equally likely to play a role in the development of applied technological innovation. Research conducted by CHI Research[9] indicates that the publicly funded research papers most cited in US patents are preferentially drawn from the most highly cited, high-quality research. A US research paper in the most highly cited 1 per cent of scientific papers is 9 times as likely to be cited in a patent as a randomly chosen US paper.

Evidence in the field of biological science suggests that the ARC's focus on excellence has translated into superior outcomes in terms of generation of the highly cited papers that are most likely to provide the basis for the development of new patented technology. Papers produced by ARC Centres and by ARC Grantees are respectively 4 and 3 times more likely to be in the top 1 per cent of cited papers as papers produced in universities where the researchers were not recipients of ARC funding[10].

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[5] Smith and Barfield (1996)
[6] See for instance Adams (1990) and Smith and Barfield (1996)
[7] Narin (1997)
[8] Narin (2000)
[9] CHI Research (2000)
[10] Grigg (1999)

An OECD study into R&D and productivity[11] has pointed to benefits associated with funding for research being allocated on a project basis (as occurs with most ARC funding). This study suggested that this allocative approach provides greater flexibility to adjust resource allocation towards promising emerging fields of research which, in turn, may have a bigger impact on productivity.

The ARC's focus on excellence suggests that the benefits from building the basic knowledge stock associated with ARC funding are likely to be higher than the average benefits associated with public research funding. Furthermore, the linkage between basic knowledge and subsequent applied technological advances suggests that benefits from the ARC's funding of basic knowledge generation may be considerable. However, the key challenge remains to estimate the scale of these benefits. Our approach to addressing this challenge and the findings from our investigations in this area are reported in section 6 of this report.

Benefits from generation of directly commercialisable intellectual property

In recent years considerable attention has been focussed on the returns being generated from the commercialisation of public sector R&D. In Australia, the ARC, CSIRO and NHMRC sponsored a national survey of research commercialisation[12], the Prime Minister's Science, Engineering and Innovation Council has released a working paper examining commercialisation of public sector research[13] and DEST has recently released a report into best practices for university research commercialisation[14].

Consideration of these studies leads to the conclusion that relatively little of the benefits of commercialisation of public sector R&D tend to be captured by the institutions that performed the research. Total revenues for publicly funded research institutions associated with the formation of spin-off companies and from intellectual property licensing are small in comparison to total levels of expenditure on R&D. For instance, the National Survey of Research Commercialisation found that total licence fee revenues for universities, the CSIRO and NHMRC-funded medical research institutes totalled $99 million in 2000. This compares to the $3.7 billion spent on research by these institutions in 2000. Equity held by these institutions in start-up companies was also relatively low, estimated at $119 million in 2000.

The national survey and the recent DEST report also indicate that, while overall Australian performance may lag somewhat behind best practice in the area of generating commercialisation revenue, even if Australian institutions reached best practice levels the total level of commercialisation revenue would remain very small relative to research expenditures. While improving commercialisation practices could perhaps double revenues, it is unlikely that revenues to these institutions would be able to be increased much further.

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11 OECD (2001)

12 ARC, CSIRO, NMHRC (2002)

13 PMSEIC (2001)

14 Australian Centre for Innovation, Howard Partners, Carisgold (2003)

Given this, in assessing the commercialisation returns associated with ARC research funding, it would not appear that high returns are likely to be found in the area of revenues accruing to institutions. However, it is possible that the returns to institutions associated with ARC-funded research are significantly higher than the average return on total research expenditure. This is because the majority of commercialisation returns to institutions tend to come from a small number of successful commercialisation activities. The DEST study cites the case of Yale University, where a review of its 850 invention disclosures between 1982 and 1996 found that 1 per cent of the disclosures generated 70 per cent of revenues and that 4 per cent of the disclosures accounted for 90 per cent of revenues. A similar concentration of returns on a small number of projects was found in the national survey of research commercialisation. Of the $88.3 million in licence fee revenue received by universities in 2000, $50 million came from one source – Melbourne IT. If investigation of the key major commercialisation successes reveals that one or more of these successful projects received funding from the ARC at the research stage, the commercialisation returns to research institutions linked to ARC funding may be significantly above the low average returns to those institutions witnessed for publicly funded research.

Notwithstanding the prospect that commercialisation returns to institutions linked to ARC funding may be of some significance, it is likely that the major returns from commercialisation of ARC-funded research have not been fully captured by the universities where the research was conducted. A wider consideration of the economic impacts associated with the direct commercialisation of ARC-funded research is therefore needed. There are a number of instances in Australia of companies being formed, as a direct result of publicly funded research, that have grown to make a substantial economic contribution in terms of employment, value added and exports. Resmed, Cochlear, Vision Systems and Radiata are examples of such companies that would not have existed in the absence of intellectual property generated by publicly funded research.

In order then to determine the benefits from direct commercialisation of ARC-funded research, it is necessary not only to identify returns that have flowed back to institutions through licence fees and equity in spin-off companies but also (and more importantly) to consider the economic impacts associated with companies that have been based on the direct development of ARC-funded research into commercial products and services. Our approach to investigating these two sources of economic benefits and the results from our investigation are detailed in section 6.

Benefits from improving the skills base

The 1999 White Paper, *Knowledge and Innovation*, placed great emphasis on the fact that the universities are the key providers of training and professional development for Australia’s future researchers.

An important contribution made by the ARC is associated with its role in funding research training and the development of skills, through participation in ARC-funded projects by PhD, Masters and Honours students. Further, researchers funded by the ARC undertake teaching in universities at the post- and under-graduate levels, thereby disseminating the knowledge they accrued from funded research to their students. ARC funding also allows better quality academics to be attracted to and retained in Australian Universities.

A skilled workforce can influence long-run growth and productivity in a number of ways. While there are obvious direct benefits to the individual from a higher skill level (through increased wages) there is an increasing appreciation of how investment in skills generates broader public economy-wide benefits through increasing productivity and long-run economic growth.

While investment in human capital has a direct (private) benefit to the individual in the form of increased returns (wages), it can be argued that a worker's skill will influence not only their own productivity, but also the productivity of their colleagues. Therefore, there are external productivity benefits from an individual's skill level over and above those attributed directly to the individual and captured in his or her wage level. Further, there are network externalities involved with skill development. For example, the benefits derived from being able to read and write are greater given others have the same skills. Therefore, increasing average skill level across the workforce can drive labour productivity and economic growth higher.

As individuals learn and acquire more skills, it becomes easier for them to acquire further knowledge. Economies with a higher average skill level are more likely to be able to take advantage of emerging domestic and international technologies (absorb technology), as they have the existing skills to be able to understand the new technology, and recognise potential uses for it. These new technologies provide for greater productivity growth in the economy.

While skill development is inherently embodied in the individual (and is lost when that individual dies), the idea of disembodied human capital provides for continuing growth in knowledge and can drive economic growth. Disembodied capital is the world of knowledge and ideas that, once released in the public domain, have similar properties to public goods. Once this information has been released into the world, others are able to access it and use it as the foundation for further development of ideas. Therefore, disembodied capital has public good properties, such as non-rivalry, and is cumulative. In particular, knowledge is cumulative in the area of 'basic' research (as opposed to more applied research linked to industry) where each additional discovery in an area can lead to development of further work and so on.

In measuring the benefits from skills formation due to ARC funding, it is therefore important to look beyond just the value that the market puts on the skills of postgraduates in terms of their higher wages[15]. It is also necessary to consider the extent of spill-over benefits generated through the improvements made to the skills base by ARC funding activities.

Benefits from improving access to international research

A number of econometric studies have demonstrated that foreign knowledge is an important driver of technological progress for any national economy. A recent OECD study of sixteen economies found that a 1 per cent increase in the level of foreign R&D generates on average a 0.44 per cent increase in productivity growth in a national economy[16] (although the OECD study acknowledges that other studies have found somewhat lower elasticities of around 0.30).

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[15] ABS data (ABS Catalogue 4230.0 unpublished data) shows that in Australia average full-time weekly earnings for those with postgraduate degrees or graduate diplomas are $1,235 per week (11 per cent higher than those with bachelor degrees).

[16] OECD (2001)

This study highlighted that there are a number of ways that a country can benefit from research conducted in other countries. Companies can utilise productivity-improving products and processes developed overseas (for instance IT tools), buy patents, licences and know-how from foreign firms, they can hire foreign engineers and scientists, reverse engineer products available overseas, read international scientific and technical literature or have direct contacts with foreign engineers and scientists at conferences.

The OECD paper also highlighted that, for a country to take full advantage of foreign R&D, it must also actively invest in its own R&D activities. The 'free rider' approach does not work because, in order to benefit from foreign R&D, you must have the domestic capacity to not only access but absorb and adapt the foreign R&D. Such capacity is developed only through a country undertaking its own R&D activities[17].

The ARC contributes both to Australia's ability to access foreign R&D and our ability to absorb and adapt foreign R&D. It indirectly improves Australian industry's ability to absorb and adapt foreign R&D due to its important role in building the research skills base in Australia. The funding activities of the ARC also directly act to increase Australia's access to foreign R&D. For instance, in 2002 the ARC awarded 66 new international linkage grants (totalling $2.7 million) which provide support for the movement of researchers between Australian research institutions and centres of research excellence overseas. In addition, 136 of the Discovery-Projects grants commencing in 2002 involved a named investigator from overseas.

The key challenges in estimating the scale of the benefits associated with improving access to foreign knowledge are to determine to what extent ARC-funded projects involve international collaboration and to determine the value of the access to foreign research to which these projects allow. Another challenge in estimating the scale of benefits associated with ARC funding improving Australia's ability to absorb and adapt foreign R&D is to determine the strength of the link between domestic R&D capacity and the ability to benefit from foreign R&D and the significance of the ARC in building this capacity. In section 6 our approach to addressing these challenges and the findings from our investigations in this area are reported.

Benefits from better informed policy making

An area of benefits from publicly funded research that has appears not to have been subject to close examination is the impact of publicly funded research on the formation of government policy in areas such as economics, health, education and the environment. One reason why there appears not be an existing body of research in this area is that it is very difficult to establish both what information inputs drive public policy development and what social and economic outcomes can be linked to particular policy decisions. Despite these methodological difficulties, there is reason to believe that the benefits flowing from policy decisions, that have been in part shaped by the results from publicly funded research, may be significant.

[17] UNIDO (2002), provides further support for the importance of having a domestic skills and knowledge base if foreign technology is to be successfully utilised.

For instance, the Productivity Commission, in an investigation of Australia's productivity performance, claims that much of Australia's surge in multi-factor productivity (MFP) growth between 1993 and 1998 could be attributed to microeconomic reforms undertaken during the mid to late 1980s[18]. During this period MFP growth was 1.2 per cent per annum higher than the average for the preceding 30 years. While, as the Productivity Commission itself acknowledges, it is very hard to establish the extent to which microeconomic reforms (such as reductions in tariffs, changes to the taxation system, provision of incentives for business R&D and industrial relations changes) drove this productivity surge, even if microeconomic reform accounted for half of this productivity increase over historical levels[19] the impact of these reforms would equate to GDP being $15 - 20 billion higher in 1999[20] than it would have been without such microeconomic reforms occurring.

Clearly, if ARC-funded research was even a small driver of the adoption of microeconomic reform policies, there is the potential for significant economic impacts being attributable to ARC-funded research. Given that ARC funding has been provided to those involved in the development of economic models that have been used by the Productivity Commission (and its predecessor the Industry Commission) to make the case for microeconomic policy reform, it is arguable that the ARC has been a contributor to the benefits of policy reform in this area.

It is also possible that ARC-funded research has made a contribution to improved policy making in a number of other fields such as education policy, health policy, welfare policy and so on. However, as outlined in section 6, due to the difficulties associated with quantifying these benefits, it is necessary to take both a qualitative and quantitative approach to considering benefits in the area of policy making.

Health, environmental, social and cultural benefits

The health, environmental, social and cultural benefits generated by public research and development activities may be of considerable economic significance. Improving health outcomes through biological and social science research may increase labour force productivity and directly reduce health expenditures. Research in the environmental sciences may help mitigate the impacts of land degradation and thus improve agricultural productivity. Research in the humanities may increase social cohesion through establishing a greater level of understanding of ourselves as individuals and as members of society, which in turn could reduce costs associated with anti-social behaviour.

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[18] PC (1999). See also Parnham, D., (1999), Parnham, D., (2002a) and Parnham, D., (2002b)

[19] Parnham, D. (2002a) argues that up to 80 per cent of this productivity spike is attributable to microeconomic reform.

[20] Assumes that GDP growth was 0.6 per cent per annum higher between 1993 and 1998 than it otherwise would have been.

Benefits of these kinds are potentially amongst the most economically significant of all the benefits associated with publicly funded research. In 2000, a group of economists authored a major study in the United States that attempted to quantify the value of medical research in the United States[21]. The primary focus of the study was not on the value of commercialisation of research by pharmaceutical companies (in this report we consider such benefits under the category of benefits from commercialisable intellectual property) or the increased cost-effectiveness of medical treatment or even the increased productivity associated with healthier workers. Rather the study attempts to quantify the value people place on living longer and healthier lives. The authors of the study found that the value of such benefits were enormous. Box 3.1 sets out a few of the key findings from this study.

Box 3.1

RETURNS ON US INVESTMENT IN MEDICAL RESEARCH

Increases in life expectancy in the 1970s and 1980s were worth US$57 trillion to Americans.

Improvements in health account for almost one-half of the actual gains in American living standards in the past 50 years.

Medical research that reduced deaths from cancer by just one-fifth would be worth US$10 trillion to Americans.

Source: www.fundingfirst.org

Unfortunately, it is not possible within the time constraints of this study either to readily quantify the environmental, health, social and cultural benefits occurring in Australia due to R&D activity or to determine the extent to which ARC-funded research contributes to such benefits. However, it is likely that ARC-funded research has generated substantial benefits in each of these areas. For instance:

- in the area of health benefits, ARC funds have been important in the ongoing development of a rotary blood pump, that, in addition to potentially resulting in significant sales of the blood pump (covered in this report under the heading of direct commercialisation of intellectual property), has the potential to improve health outcomes of those waiting for heart transplants. Reducing the death rate from congestive heart failure would carry large human and economic benefits.
- in the area of environmental benefits the ARC has funded research into the ecology and evolution of corals that will improve the long-term environmental management of the Great Barrier Reef, one of Australia’s leading tourist attractions; and
- in the area of social benefits the ARC has supported the development of greater understanding of indigenous (as opposed to Western) styles of helping. This study has led to a rethinking of the application of mainstream western helping styles to indigenous communities and the development of a new curriculum for social welfare students. This in term may lead to improved outcomes in terms of rates of assault, child abuse and domestic violence in indigenous communities.
- in the area of cultural benefits The University of Melbourne Conservation Service commenced operation at the Ian Potter Art Conservation Centre in 1989. The Service was established in recognition of the University’s need to provide for the preservation of its extensive and significant collections of cultural material.

[21] Mary Woodward Lasker Charitable Trust (2000), *Exceptional Returns: The Economic Value of America’s Investment in Medical Research*, summary of report findings accessed at www.fundingfirst.org

Section Four

Methodology for measurement of benefits from ARC research funding

This section sets out the two methods that are being used in this study to provide quantitative estimates of the benefits generated by ARC-funded research and the rate of return on the Commonwealth's investment in such research. The development of these methods has been informed both by the existing Australian and international literature on the subject and by consideration of the specific situation of the ARC and the available data in relation to the benefits of ARC funding.

4.1 Outline of two approaches to measuring benefits

In this study two distinct approaches have been adopted to attempt to quantify the social and economic benefits associated with ARC-funded research activities in Australia.

The first approach, the 'top down' approach, is designed to generate a reasonably conservative benchmark figure for the impacts of ARC research funding based on a review of Australian and international studies on the relationship between funding for R&D and economic productivity growth. Box 4.1 explains the link between productivity growth and increasing living standards. This productivity analysis approach is not based on a specific analysis of observed impact of ARC research funding in Australia, rather it is based on analysis of the average observed impact of various types of research funding on productivity growth in Australia and other developed economies. This 'top down' analysis is intended to provide a 'benchmark' estimate of impacts of ARC research funding.

Box 4.1

USE OF PRODUCTIVITY ANALYSIS IN ASSESSING THE BENEFITS OF ARC RESEARCH

Productivity growth is a measure of the growth in the ratio of output to inputs (labour and capital). Evidence of productivity growth usually means that better ways have been found to create more output from given inputs. While the concept of productivity growth in itself appears relatively abstract, there are key linkages between productivity growth and improvements in living standards and long-term economic performance. Productivity growth is a crucial source of growth in living standards.

In order for a nation to raise its material standard of living it must produce more. It can do this by increasing the amount of inputs in production – by increasing hours worked by employees, or the amount of capital – or by becoming more efficient – by improving the quality of capital and equipment or by using more highly skilled workers. Using more inputs incurs a cost, whereas increasing the efficiency of production can lead to higher income from production. This higher income means higher wages, increased profits and more taxes for government. In a high income economy investments can be made in education, public health and infrastructure to enhance the standard of living.

Productivity growth has accounted for about two-thirds of the improvement in real average incomes of Australians over the past three decades.[22]

Therefore, in assessing the benefits derived from ARC research, determining the contribution of ARC research to productivity growth links how ARC research contributes to the long-term performance of the economy, and growth in the standard of living.

Source: Allen Consulting Group analysis

[22] Industry Commission (1997)

A broad precedent for using an approach along these lines was set by the Industry Commission in its 1995 report on R&D[23]. The Industry Commission presented a broad estimate of the social returns to R&D in Australia. Its estimate was based on a direct comparison of productivity at the national level with R&D effort, to derive a measure of the social rate of return to all (public and private) R&D.

The second approach which we have adopted, the 'bottom up' approach, involves a more complex analysis of the specific impact of ARC research funding in Australia. This approach involves examination of the level of benefits in each of the areas discussed in section three that can be traced to ARC research funding. Under each category of benefits, ARC funding over the past decade is examined and links between that funding and benefits generated are considered. This 'bottom up' approach is highly specific to the Australian environment and yields results that are as accurate an assessment of the returns on ARC research funding as can be obtained given available data. It should be noted however that, due to the fact that not all possible areas of benefits have been able to be measured in this study and the fact that throughout this report we have used conservative assumptions in measuring returns on ARC funding, the measured returns on ARC funding should be seen as being as approximating a 'lower bound' estimate of returns.

The results from the 'bottom up' analysis can then be compared with the benchmark figure generated through the 'top down' analysis. For the results of the 'bottom up' analysis to be credible it is necessary to be able to explain the reasons underpinning any divergence in results compared to the results that would be expected if the impacts of ARC funding conformed to the average results associated with comparable research funding in other developed economies.

The methodologies involved in the two types of analysis undertaken in this study are set out below.

4.2 'Top down' approach

The 'top down' approach is based on an analysis of the drivers of productivity growth in developed economies. The sources of productivity growth can in broad terms be categorised under three categories:

- growth in capital inputs;
- growth in labour inputs; and
- a residual factor (multi-factor productivity growth) that can perhaps best be described as technological progress.

If the level of growth in output of the economy was equal to the growth in inputs of capital and labour inputs, there would be no residual factor. However, in developed economies not all output growth can be accounted for simply by the increase in inputs going into the economy. The quantity of growth in output does in fact tend to increase at a greater rate than the growth in the quantity of capital and labour inputs. This residual factor is called the rate of multi-factor productivity (MFP) growth. In essence, something is occurring within the economy that allows a greater level of output to be generated from the available stock of inputs. A catch-all term used to describe the source of this efficiency increase is 'technological progress'.

[23] Industry Commission (1995). See quantitative appendices QA, *Quantifying the return to R&D: The evidence to date* and QB, *Productivity growth and the returns to R&D in Australia*.

The 'top down' analysis we have conducted in this study involves three steps. The first is to establish, based on assessment of available Australian and international studies into the drivers of MFP growth, the extent to which all research and development (public, private and international) contributes to MFP growth. The second step is to estimate the contribution to MFP growth made by Australian publicly funded research and development. The third step is to determine the share of the impacts of public funding for R&D in Australia that can be attributed to the funding activities of the ARC.

Once these three steps have been completed, it is then possible to provide an estimate of the share of Australian MFP growth that can be attributed to the research funding provided by the ARC.

It must be stressed though that the results of the 'top down' analysis, because they are based on the average impacts of research funding in a number of developed economies, should be viewed as providing a plausible order of magnitude of the impact of ARC research funding rather than a precise figure based on detailed consideration of the links between ARC funding and associated benefits that have been observed in Australia. The generation of such Australian-specific results requires application of the 'bottom up' analysis that is detailed below.

4.3 'Bottom up' approach

The 'bottom up' approach to estimating the social and economic impacts of ARC research funding involves examination of each of the areas of benefits associated with its activities that were identified in section 3. Under each of these benefit areas we estimate the extent of the benefits that flow to Australia due to ARC funding of research. In order to develop these estimates we have reviewed available relevant literature surrounding each of the areas of benefits and have also developed a set of case studies exploring outcomes associated with ARC funding activities.

Once the level of benefits in each of the areas (associated with ARC funding activities) has been estimated, we express these benefits in terms of their contribution to MFP growth in Australia. The impact of this contribution to MFP growth can then be modelled through the CoPS[24] general equilibrium model of the Australian economy to provide estimates of the impact of ARC research funding on social and economic outcomes in areas such as employment, income levels and government finances (details of modelling scenarios are set out in section 7).

It should be noted that undertaking the 'bottom up' analysis requires judgements to be made on some important aspects for which data are limited. Judgements have had to be made regarding both the extent to which benefits exist in a given area and the extent to which these benefits can be linked to the activities of the ARC. In making such judgements we have sought to make conservative and defensible assessments. Details regarding the findings of our investigations in each of the areas of benefit discussed in section 3 are set out in section 6 of this report.

[24] The Centre of Policy Studies at Monash University is a research centre with national reach focussing on economic modelling. Its Computable General Equilibrium (CGE) model of the Australian economy will be used to model the economic impacts of ARC-funded research

Section Five

Findings from ‘top down’ approach to quantifying benefits from ARC research funding

This section presents the findings of the literature with respect to identifying determinants of multi-factor productivity (MFP) growth. In this section we identify:

- the key drivers of MFP growth;
- the contribution of all R&D to MFP growth;
- the relative contribution of public R&D to MFP growth within advanced economies; and
- through consideration of the characteristics of ARC funding activities, an analysis has been conducted to generate a theoretically justifiable estimate of the contribution of ARC research funding to Australian MFP growth during the 1990s.

The results of this analysis are then converted to an estimate of the dollar impact on GDP associated with ARC research funding during the 1990s.

Once the contribution to GDP (measured in terms of the extent to which GDP is higher by the end of the 1990s than it would have been without ARC funding) made by ARC funding has been estimated it is then possible to compare this to the total value of ARC funding made during the 1990s. This gives us the social rate of return on ARC funding. The social rate of return is defined as the increase in GDP as a percentage of the dollar cost of the investment that lead to this increase.

5.1 Overview of findings from Australian and international literature

An extensive literature review has been conducted with the objective of establishing estimates of, firstly the share of MFP growth attributable to all (public, private and international) R&D, then the contribution of all public funding of R&D in Australia and finally the share of MFP growth attributable to the funding activities of the ARC. In order to develop these estimates we first needed to establish the extent of MFP growth and what it measures, and the extent to which all R&D contributes to MFP growth. The findings of the literature review are set out below.

Measuring MFP growth

Boskin and Lau[25] have highlighted that measurement of the size of the residual, which is seen as an indicator of the impact of technological progress, within growth accounting is heavily impacted by whether measures for capital and labour inputs attempt to include changes in the quality of capital and labour inputs. They find that, in studies where the values for capital and labour inputs have been quality-adjusted, the average proportion of economic growth attributed to the residual is 25 per cent, whereas, in studies where the values for capital and labour inputs have not been quality-adjusted, the average proportion of economic growth attributed to the residual is 52 per cent. In assessing the Australian data in relation to the residual (defined as MFP in Australian data) it is therefore important to know the extent to which the impacts of technological progress have been incorporated in the data for capital and labour inputs.

The Industry Commission explored this issue in 1995[26] and found that in Australia the ABS employs a range of computational techniques that results in estimates of multi-factor productivity partially excluding the impacts of technological change and quality improvements in labour and capital. The ABS has recently changed the capital input measure to a capital services measure to incorporate further quality changes. While there has not been any quality adjustment of labour input made as yet, we understand that the ABS is doing further work in this area.

Clearly, the figures for multi-factor productivity do not fully reflect the economic impact of technological progress, as part of the benefits are incorporated into the values for capital and labour inputs. This suggests that, in Australia, to get a true measure of the importance of technological progress to economic growth it may be necessary to include some of the contribution of capital and labour inputs to economic growth, in addition to looking at the value of multi-factor productivity, when calculating the value of technological progress to economic growth.

However, given that it is not possible to determine to what degree the values for capital and labour incorporate improvements in quality due to technological progress, in relation to our calculations of the contribution of public R&D to economic growth we have taken the conservative assumption that the multi-factor productivity figures for Australia do in fact capture the value of technological progress to Australia's economic growth performance. This may result in a bias towards under-estimating the contribution of public R&D to economic growth.

The Productivity Commission has reported that market sector multi-factor productivity growth in Australia between 1993-94 and 1998-99 averaged 1.8 per cent per annum, while total output growth for this period was 4.7 per cent per annum. MFP growth therefore represented almost 40 per cent of total output growth during this period[27].

The contribution of all R&D to MFP growth

In debates surrounding the development of R&D policy, those arguing for an increased commitment to R&D have highlighted the fact that technological progress is responsible for around half of economic growth in developed economies[28].

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[25] Boskin, M., and Lau, L., (1996)

[26] Industry Commission (1995), Appendix QB4

[27] Productivity Commission, Market sector aggregate productivity update, accessed at www.pc.gov/work/productivity/marketsector.html

[28] See for instance Chief Scientist (2000), pgs 15 and 20

Some, such as Tassey[29], suggest that R&D is in fact the key driver of technological progress/MFP as it is the process by which new technology is created. However, while there is good reason to believe that R&D is an important driver of MFP growth, it is by no means the only contributor to MFP growth. Other potentially significant contributors are increases in the quality of the skills base (to the extent that this is not captured within values for labour inputs), improvement in economic structures that increase efficiency of resource allocation, increases in world population (that provide a larger export market and therefore provide greater economies of scale) and improvements to productivity due to organisational innovation and learning by doing.

In a detailed econometric assessment of the contribution of R&D to economic growth, Boskin and Lau attempted to isolate the impact of the R&D capital stock on economic growth[30]. They found that across a range of developed countries the stock of R&D capital accounted for between 10 and 15 per cent of economic growth. However, it is important to note that analysis of a number of technical constraints on the modelling led them to conclude that these figures were likely to systematically under-estimate the impact of R&D. Problems included dealing with the time-lags involved in the realisation of benefits from R&D, difficulties in measuring the impact of R&D activity on skills formation and the quality of capital and the fact that R&D sold to the public sector is measured on an input cost basis where no productivity growth is assumed.

Given these constraints, they concluded that, while R&D is important to economic growth, it is not possible to determine exactly how important it is. However, based on consideration of the findings of their econometric studies and their discussion of the downward bias within their results, it would seem that the contribution of R&D to economic growth is likely to be somewhat greater than 15 per cent. Within the context of Australian productivity performance in the 1990s, this would suggest that R&D is likely to have been responsible for approximately half of multi-factor productivity growth (which itself accounted for around forty per cent of total output growth between 1993-94 and 1999-00[31]).

The contribution of public R&D to MFP growth

If we accept that a reasonable estimate of the contribution of R&D to MFP growth is around fifty per cent, we still need to determine the different impacts associated with public, private and foreign R&D. A recent OECD study sheds some light on this issue. A review of the link between R&D and productivity growth in 16 OECD countries separately measured the elasticities[32] between productivity growth and levels of domestic business R&D, domestic public R&D and foreign R&D. It found that the elasticity between domestic business R&D and output (0.13) was slightly lower than that between domestic public R&D and output (0.17), but that in turn this elasticity was less than half that found between foreign R&D and output (0.44)[33]. The research also considers some reasons for variance between countries, which suggest that for Australia, where university R&D accounts for a large share of public sector R&D and where business R&D is relatively low, the relative impact of public R&D, as a share of total impacts of all R&D, is likely to be slightly higher than average.

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[29] Tassey, G., (1995)

[30] Boskin, M., and Lau, L., (1996)

[31] Productivity Commission, Market sector aggregate productivity update, accessed at www.pc.gov/work/productivity/marketsector.html

[32] The 'elasticity' measures the percentage change in output associated with a 1 per cent change in the level of a particular type of R&D

[33] OECD, (2001)

Given that the relative marginal impacts (of foreign, domestic business and domestic public R&D) are likely to be similar to their relative average impacts, and given that public and business expenditure on R&D in Australia are of very similar magnitude[34], it therefore appears reasonable to attribute about 25 per cent of the contribution of R&D to MFP growth in Australia to publicly funded R&D. This suggests that in Australia publicly funded R&D can be expected to be the driver of around 12.5 per cent of Australian MFP growth.

Establishing the share of MFP growth attributable to the funding activities of the ARC

If ARC funding were expected to generate similar returns to the average returns associated with all public R&D, establishing the share of MFP growth attributable to ARC-funded research would be very straightforward – assuming of course that one accepts as reasonable the estimate that publicly funded R&D drives 12.5 per cent of MFP growth. Estimating the contribution of ARC-funded research would simply involve calculating ARC funding as a percentage of total public funding of R&D and applying this percentage to the 12.5 per cent figure. For instance, in 1998-99 the ARC funding of almost $240 million represented around 5.2 per cent of total public R&D funding. Therefore, if ARC funding was expected to generate similar rates of return as the average for all public R&D funding, the share of MFP growth attributable to ARC funding would be estimated at approximately 0.65 per cent.

There is, however, a number of reasons why ARC funding could be expected to generate significantly higher returns over the longer term than the average returns for all public funding of R&D. These include:

- ARC funding is allocated on the basis of research excellence by use of a competitive process, implying that the ARC is likely to fund only the best available research activities. Available evidence suggests that ARC-funded research does in fact produce output of higher impact than other publicly funded research. For instance, in biology, papers produced by ARC Centres and by ARC Grantees are respectively 4 and 3 times as likely to be in the top 1 per cent of cited papers as papers produced in universities where the researchers were not recipients of ARC funding[35].
- ARC funding programs allow the ARC to respond to emerging high-potential fields of research more rapidly than occurs with public sector research funding directed to institutions, such as University research block grant funding and the appropriation funding for the CSIRO[36];
- ARC research funding is more heavily focused on supporting ‘breakthrough’ research, which the international literature suggests has higher rates of spillover benefits than other forms of public R&D funding such as the Co-operative Research Centres, the R&D tax concession scheme and the R&D Start Grants which tend to support ‘incremental’ and ‘next generation’ R&D;

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[34] DEST (2002), *Australia Science and Technology at a Glance*. Using constant 2001-02 dollars, DEST reports that in 1998-99 Government R&D funding totalled $4.6 billion while Business R&D expenditure totalled $4.3 billion.

[35] Grigg (1999)

[36] It should be noted, however, that the ARC generally provides only a part of the funding for research projects. Often ARC grants involve Universities making matching (or higher) contributions to total project costs from their block grant funding. This ‘drag through’ of other forms of public sector funding will to an extent narrow the performance gap between ARC research funding and other forms of public funding such as the university research block grants.

- the ARC tends to fund high-potential research at the early, riskiest stages of the innovation process. Therefore, even when other funding is later provided from sources such as Co-operative Research Centres and the R&D Start Grants program, it may be that the ARC funding is relatively more important in enabling the development of resulting intellectual property. This is analogous to the returns on funds that are expected by venture capital investors at different stages of company formation. Early-stage providers of seed funding receive a much lower equity entry price than later-round providers of finance. This is because they are contributing funds at a riskier stage in the business development process;

- the ARC funds infrastructure and projects that assist in the training of a high number of postgraduate researchers, suggesting that the ARC plays a relatively significant role in the generation of benefits from improving the skills base; and

- ARC funding allows leading-edge equipment to be purchased which is then available for use by researchers on other projects.

As a result of each of these factors, it is highly likely that the returns on ARC funding are significantly higher than the average return on all public R&D investment, which includes University block grant funding, Co-operative Research Centres, R&D Start Grants, R&D tax concession scheme, funding of institutions such as the CSIRO, individual State Government grant programs and so on. Noting the findings of citation studies, we believe that a conservative estimate of the returns on ARC funding could be expected to be twice the average returns associated with all public funding of R&D. Applying this multiple would suggest that, rather than ARC driving 0.65 per cent of MFP growth, it in fact drives around 1.3 per cent of MFP growth in Australia[37].

5.2 Estimating the rate of return on ARC funding

The estimate that ARC research funding drove around 1.3 per cent of MFP growth in Australia during the 1990s can be translated into a social rate of return figure for ARC research funding. This rate of return can be assessed against findings from other studies into the rate of return on R&D funding.

The social rate of return on R&D is the permanent increase in national output generated by investment in R&D. For instance if a nation invests $1 in R&D and this results in a 50 cent permanent increase in national output (over and above the $1 of R&D output recorded in the year the R&D investment is made), the social rate of return of the R&D investment would be 50 per cent.

[37] Possible counter arguments against the proposition that ARC funding has greater impacts than the average for all publicly funded R&D are that:

- ARC funding spans a broad range of fields, some of which are not likely to generate significant economic impacts;
- investigator-initiated research such as much of that funded by the ARC may not be oriented towards generating economic outcomes; and
- given that ARC research funding is often ‘breakthrough’ research there is a higher risk of failure.

These arguments are however not convincing. Regarding the first point, as was set out in Section 2, one of the consequences of the funding model used by the ARC is that it primarily funds projects rather than research institutions and it is therefore more readily able to direct resources to emerging areas of research with high potential. In relation to the second point, it must be noted that it is the quality of research, rather than its explicit orientation, that is the key predictor of eventual value and that the ARC produces higher than average outcomes in terms of research quality measures. Finally, the impact of ARC-funded research is actually enhanced by the fact that it tends to be primarily directed at ‘breakthrough’ research. Such research, while characterised by high risk, is also associated with much higher returns if successful. The returns to society from incremental and intermediate research which are the provinces of the other elements of the research system are likely to be lower risk but also likely to offer lower returns.

Table 5.1 sets out the calculation of the permanent increase in GDP in Australia between 1990-91 and 1999-00 and the proportion of this output growth that was due to MFP growth in Australia during the period. It converts this to the dollar value of the associated permanent increase in GDP over the decade due to MFP growth. It then compares the share (estimated at 1.3 per cent) of this growth driven by ARC activities against the total level of funding for the ARC's activities during the 1990s to give an broad estimate of the social rate of return on ARC activities during the 1990s[38].

Table 5.1

ESTIMATED SOCIAL RATE OF RETURN ON ARC FUNDING DURING THE 1990s

ncrease in GDP ›etween 1990-91 and 1999-00 ($ million)[1]	Approximate share of ıcrease due to MFP growth[2]	Increase in GDP due to MFP growth ($ million)	Increase in GDP due to ARC activities ($ million)[3]	ARC funding ($ million)[4]	Approximate Social rate of return on ARC funding between 1990-91 and 1999-00[5]
$232,800	40%	$93,120	$1,210	$2,350	51.5%

[1] Based on figures in Table 3 in DISR*, Science and Technology Budget Statement, 2000-01*. Note that these GDP growth figures are nominal rather than in constant 1990-91 dollars. Given that the ARC funding figures in column five are also in nominal dollars rather than constant 1990-91 dollars the use of nominal GDP figures is appropriate for calculating the social rate of return on ARC funding - use of 'real ' GDP growth and 'real' ARC funding figures would give the same proportional result as using nominal figures for both variables.

[2] Based on Productivity Commission, Market sector aggregate productivity update.

[3] Assumes 1.3 per cent of increase in GDP due to MFP growth is driven by ARC activities.

[4] Based on data provided by the ARC.

[5] Calculated as permanent increase in GDP divided by total of ARC funding over the period.

As the calculations set out in Table 5.1 indicate, based on our 'top down' analysis the estimated social rate of return on ARC funding during the 1990s is around 50 per cent.

Findings from other studies into rates of return on R&D funding

Within the economic growth literature, in addition to studies focused on the extent to which R&D drives productivity growth (which were discussed above), another (related) approach to measuring returns on investment in R&D features prominently. Studies have attempted to measure the economy-wide social rate of return on R&D investment[39].

[38] It should be noted that this is only a rough calculation of the rate of return on ARC activity as it does not factor in the time lags involved in the generation of pay-offs from the ARC research funding. This issue is addressed in more detail in the modelling set out in section 7 of this report. Given that the figures for ARC funding and GDP growth are both based on year-by-year actual dollar figures, issues surrounding constant versus real dollars are, however, not an issue in these rough calculations of rate of return.

[39] Another closely related approach has been to measure the elasticity between R&D and output growth. The elasticity between the R&D capital stock and the level of output refers to the percentage change in output associated with a 1 per cent change in the level of R&D. For instance, if a 1 per cent increase in R&D investment leads to a permanent increase of 0.1 per cent in output, then the elasticity of R&D investment is 0.1. In relation to the link between increases in R&D and increases in output, Griffith, Redding and Van Reenen report that studies typically indicate that a 1 per cent rise in the stock of R&D leads to a rise in output of 0.05 to 0.15 per cent (Griffith, R., Redding, S., Van Reenen, J., (1998)). Cameron reports a similar result from his review of the existing literature, suggesting that a 1 per cent rise in the stock of R&D leads to a rise in output of 0.05 to 0.10 per cent (Cameron , G., (1998)).

In 1995 the Industry Commission found that, depending on the methodology used, the economy-wide social rate of return to R&D in Australia could be measured at between 25 and 90 per cent[40]. Dowrick, in a review of international literature[41], reports that estimates of the national rates of return on R&D tend to cluster around the 50 to 60 per cent level. Cameron[42] has reported that social rates of return to R&D are typically estimated at between 20 and 50 per cent. However, he also notes that studies have suggested that the returns on basic R&D (for which in Australia the ARC is an important funder) tend to be higher than returns associated with applied R&D. Salter and Martin, in a review of economic studies[43], cited studies reporting social rates of return of anywhere between 10 and 160 per cent, but with most results falling in the 20 to 50 per cent range.

It should be noted here that, in general, these studies focused either on all R&D or on private R&D. In general the social rates of return on private R&D are claimed to be higher than the average for publicly funded R&D[44]. In this study we have estimated an average return on all (rather than only ARC) publicly funded R&D in Australia of around 25 per cent, which, given it is at the low end of the estimates of returns on R&D generated by the above studies, appears reasonable.

Comparing the rate of return on ARC funding with findings from other relevant studies

The results from our top down analysis of the contribution of ARC activities to output growth in Australia resulted in an estimated social rate of return on ARC funding of 51.5 per cent over the 1990s (twice the return estimated for all publicly funded R&D in Australia). This estimated rate of return appears to be 'reasonable' given the results generated by a number of previous Australian and international econometric studies regarding the scale of economic impacts associated with R&D investment (although these studies tended to look at returns to private rather than public R&D expenditure). The findings from the top down analysis that we have conducted would therefore appear to provide a credible 'base case' figure for the returns on ARC activities. While the actual social rate of return on ARC activities, which we attempt to explicitly measure in the 'bottom up' analysis set out in section 6, may differ from the theoretically generated estimate of around 50 per cent, it is unlikely that the actual result would be outside the rate of return range of 25 to 100 per cent, respectively half and double the theoretically generated estimate of the rate of return. Findings of rates of return outside of this range would need to be justified very thoroughly in order to have any credibility.

[40] Industry Commission (1995), Appendix QB.41

[41] Dowrick, S., (2002a)

[42] Cameron, G., (1998)

[43] Salter, A. and Martin, B., (1999)

[44] Lichtenberg, F.R. (1992)

Section Six

Findings from 'bottom up' approach to quantifying benefits from ARC-funded research

This section presents the findings of the case study and other analysis (Australian and international literature and data review) that has been conducted to generate estimates of the level of benefits being generated by ARC-funded research under each of the key categories of benefits identified in section three. Summaries of a number of cases studies have been included in this section. However, to avoid weighing down the main text, full details of these and a number of other case studies conducted have been attached as Appendix One to this report.

An important note of caution is required in relation to the findings set out in this section of the report. Significant limitations in available empirical data, especially in relation to funding provided in the 1980s and early to mid 1990s, and the time constraints associated with this project have meant that, in developing estimates of the returns associated with ARC research funding, a range of simplifying assumptions have needed to be made. In making assumptions we have endeavoured to err on the side of caution. However, it must be noted that the necessary reliance on a number of assumptions means that the findings presented in this section should be viewed only as 'reasonable estimates' rather than as precise and conclusive calculations.

6.1 Benefits from building the basic knowledge stock

As was discussed in section 3, there is considerable evidence to suggest that basic knowledge generated by publicly funded research is an important input into subsequent applied technological innovation. In effect, basic knowledge delivers benefits through finding an indirect 'route to use' by end users of the new knowledge. This 'route to use' occurs most commonly through the publication of research papers. Such papers disseminate the new knowledge to a community of potential users of this knowledge.

Research conducted by CHI Research[45] indicates that the publicly funded research papers most cited in US patents are preferentially drawn from the most highly cited, high-quality research. A US paper in the most highly cited 1 per cent of scientific papers is 9 times more likely to be cited in a patent than a randomly chosen US paper[46].

[45] Narin (1997)

[46] As discussed in Section 3, evidence in the field of biological science suggests that the ARC's focus on excellence has translated into superior outcomes in terms of generation of the highly cited papers that are most likely to provide the basis for the development of new patented technology. Papers produced by ARC Centres and by ARC Grantees are respectively 4 and 3 times as likely to be in the top 1 per cent of cited papers as papers produced in universities where the researchers were not recipients of ARC funding.

A major study in 2000 into the link between Australian patenting and basic science[47] highlights the heavy usage of Australian science in Australian patenting. In addition to highlighting the heavy reliance of Australian-invented US patents on publicly funded science (with 95 per cent of the cited papers authored at publicly supported institutions), this report indicated that, while Australia produces only 2 per cent of scientific papers, 21.3 per cent of citations in Australian-invented US patents are of Australian-authored papers. This shows that, relative to total research output, Australian-invented US patents are ten times more heavily reliant on Australian science than on global science. These findings highlight the crucial importance of publicly funded domestic science to Australian patenting activity.

In its 2000 study[48], CHI Research found that, of the Australian-authored papers cited in Australian-invented US patents that listed their funding source, 266 listed the ARC as the funding source for the research while only 153 listed a specific university as the funding source. Given that the ARC provides less than 10 per cent of the total funding for university research in Australia, these results suggest that ARC-funded research finds a 'route to use' far more often than the average for all university-conducted research.

Another important further point in relation to the use of ARC-funded research in US patents by Australian inventors is that the returns the inventor expects to receive through use of this research are high. Taking out, maintaining and defending a US patent is an expensive exercise with direct costs for obtaining a patent costing around US$15,000 (which is only a small cost relative to both maintaining and enforcing a patent[49]), indicating that the inventor anticipates generating returns that are far higher than this if they expect to recoup their development costs and the costs associated with obtaining, maintaining and enforcing their patent.

Attempts to calculate the value of patents have followed a number of paths. Use of process-driven calculations based on costs of patent maintenance and rates of patent maintenance suggest that the value of patents is heavily skewed, with a relatively small proportion of patents accounting for the bulk of all value associated with patents[50].

An alternative approach to assessing the value of patents has been to assess the correlation between the value of companies and the quality of their patent portfolios. Illustrative of the link between patent holdings and company valuation, CHI Research has conducted a hypothetical stock portfolio experiment. Through choosing stocks on the basis of assessment of patent portfolio quality alone, CHI research's hypothetical stock portfolio from 1989 to 1998 outperformed the S&P 500 by a factor of three times[51].

More traditional academic econometric approaches to assessing the economic value of patents have also found a strong link between patent holdings and the value of manufacturing corporations[52].

[47] Narin, F., (2000)
[48] Narin F., (2000)
[49] PatentRatings (2001), for instance, estimates that the total aggregate costs for obtaining, maintaining and enforcing patents in the US in 1999 exceeded US$5.5 billion.
[50] PatentRating (2001) found that the top 3.1 per cent of patents account for 85 per cent of the total value associated with patents.
[51] Forbes.com, 24th June 2002, *How to Find True Value in Companies*
[52] See for instance Hall, B., (1998)

Key identified ARC contributions

This analysis suggests that ARC-funded research is likely to be relatively successful in finding a 'route to use'. However, given the varied and indirect 'routes to use' involved, it is difficult to identify all (or even most) instances where ARC-funded research has eventually found a 'route to use', either through research occurring collaboratively with industry or through the release of intellectual property (through published papers for instance) into the public domain which has subsequently been used by others to develop new (or improve existing) products or processes.

Analysis of case studies of such pathways is needed in order to attempt to quantify some of the benefits associated with ARC-funded research being usefully applied. Two examples of where intellectual property developed with support from the ARC has eventually found a 'route to use', are[53]:

- Boger Fluids, which derive their name from their discoverer, Professor David Boger. The technology, known as viscoelastic fluids, has important applications in the aluminium industry (for waste disposal) and the oil industry (for crude oil transportation). The ARC has supported this research through the ARC Special Research Centre – the Particulate Fluids Processing Centre. Major benefits come through cost savings for industry; Alcoa has partnered with Boger in developing the technology for waste disposal. Savings for the aluminium industry are estimated as at least $10 million per year for the next 100 years. The technology has also been adopted in the nickel and gold sectors. Prof Boger has also applied the technology developed for the aluminium industry to waxy crude oil transportation. Prof Boger and his laboratory worked with Delhi Petroleum in Queensland to convert a specific form of crude oil from a solid to a liquid (at room temperature) so that the $180 million Jackson to Moonie pipeline could operate efficiently

- The Jameson Cell, which is the invention of Professor Graeme Jameson from the University of Newcastle. Professor Jameson began research in 1965 into multi-phase processes. In 1986, after 21 years of research, this work resulted in the invention of a radical new device for the separation of minerals known as the Jameson Cell, which is making a major impact on the Australian mining industry. The Jameson Cell induced air flotation (IAF) device was invented for the recovery of valuable minerals in mineral processing plants. The licensing rights for the Cell were acquired by MIM Holdings Limited, Brisbane. Since that time the Jameson Cell has been installed in numerous major minerals and coal projects on the worldwide market. It is estimated that the commercial value of this technology is in excess of $500 million in export coal each year. Professor Jameson has received a total of $2.1 million in ARC funding from 1979 to 1998. He currently receives ARC funding through the Special Research Centre for Multiphase Processes.

Rate of return calculation

Based on the finding of the 1997 and 2000 CHI studies into technology patents, it appears that ARC-funded research (with over 250 Australian-invented US patents citing ARC-funded research as a key input) finds a route to use with significantly higher frequency than the average for university-conducted research as a whole.

[53] Further details regarding each of these example, as well as additional case study material, is included in Appendix One.

Given that based on patent citation analysis the top 5 per cent of cited academic research papers tend to have a high probability of finding a route to use, and that ARC-funded research is significantly more likely than the average for university research to produce such highly cited papers, it appears reasonable to assume that around 10 per cent of ARC-funded research finds a route to use and that such research (based on the level of returns identified within the above case studies and the fact that ARC-funded research is the basis of over 250 US patents) generates a social rate of return typically in excess of 100 per cent. Therefore, the overall social rate of return from ARC research funding through route to use is likely to be at least 10 per cent.

However, there can be a considerable time lag between the funding of research and the generation of benefits. In terms of route to use, the 2000 CHI study found that there is generally a lag of around 10 years between publication of a research paper and its subsequent use in a patent. Therefore the 10 per cent social rate of return is on average not likely to commence until 10 years after ARC funding is provided.

Knowledge tends to have a limited commercially useful life span. However, the benefits from knowledge do tend to continue for a reasonable period – reflected in the fact that the average economically useful life of patents is around 10 to 15 years[54]. Any returns beyond such a time period would, in net present value terms, have a very low impact due to the high risk deflator associated with benefits accruing so far into the future.

Given this, and given that in the modelling set out in section 7 we do not look at the period beyond 2018, the issue of the useful life span of knowledge is not a significant concern within our analysis of the rates of return associated with ARC-funded research. Therefore, given that our economic impact assessment does not extend beyond the medium term, our use throughout this section of the social rate of return[55] as a measure of impacts from ARC-funded research is not compromised due to the fact that knowledge does in fact have a limited useful life span.

6.2 Benefits from generation of directly commercialisable intellectual property

In some cases the outputs of ARC-funded research projects have been directly commercialised. In measuring the extent of commercialisation activity resulting from ARC research funding (and the resulting employment and financial outputs associated with this commercialisation of ARC-funded research), we have focused on analysing the results of the recent *National Survey of Research Commercialisation*[56] and the detailed case studies that have been developed for twenty ARC-funded research projects. In order to estimate the direct economic benefits associated with ARC-funded research, both those captured by the institutions where the research was conducted and those captured by companies that have directly commercialised ARC-funded research, several challenging methodological issues have needed to be addressed.

[54] See, for instance, the analysis of European patent renewals by Duguet and Lung (1997), which found that almost 100 per cent of patents are still economically active after five years, over 70 per cent of patents are still economically active after 10 years and around a third are still active after 15 years. Similarly, PatentRatings (2001) in the US has found that 84 per cent of patents issued in 1986 were maintained beyond the fourth year, 62 per cent beyond the eighth year and 43 per cent beyond the twelfth year.

[55] Defined as the *permanent* increase in GDP relative to the size of the investment.

[56] ARC, CSIRO, NHMRC, (2002)

Firstly, given the often long lead times involved in the commercialisation of research, it has been necessary to focus attention on projects that received ARC funding in the past rather than on current projects where commercialisation outcomes may not become clear for a number of years.

Secondly, because the ARC is not the only source of funding for research that has subsequently been commercialised, it has been necessary to address the issue of what share of economic benefits should be attributed to ARC (rather than other funding sources such as R&D Start grants, venture capital, industry and so on) funding for projects that have generated direct commercial benefits.

To address this issue we have adopted an approach that involves adjusting the relative importance of funding (from various sources) in generating outcomes on the basis of the stage of project development at which funding was provided. Early, and hence riskier, project funding receives an upward weighting relative to funding provided at later less risky stages of the commercialisation process. In essence, the contribution to the commercial outcome assigned to the ARC funding is a product of both the quantum of funding provided by the ARC (relative to total eventual commercialisation funding) and the degree of risk that was involved at the point where ARC funding occurred.

Key identified ARC contributions

The ARC funding of research generates returns in the area of commercialisation in two ways – firstly, through Universities generating income from intellectual property generated with the support of ARC funding and, secondly, through the commercialisation by companies of intellectual property that was developed with support from the ARC.

The National Survey of Research Commercialisation found that total licence fee revenues for universities, the CSIRO and NHMRC-funded medical research institutes were only $99 million in 2000. This compares to the $3.7 billion spent on research by these institutions in 2000. Equity held by these institutions in start-up companies was also relatively low, estimated at $119 million in 2000. These figures suggest that the commercialisation returns to Universities from ARC-funded research, even if the ARC is disproportionately contributing to commercialisable outcomes, would be relatively small – perhaps only $10 million in 2000.

Much more significant though is the economic impacts associated with the activities of companies that were established to commercialise research that was funded by the ARC (or its predecessor granting schemes). Examples of such companies include[57]:

- Cochlear: With support from the ARC's predecessor organisation, during the late 1970s Professor Clark at the University of Melbourne developed the prototype for the Cochlear implant. Cochlear was formed in the early 1980s to commercialise this technology. Cochlear now generates revenues of over $250 million per annum and has a market capitalisation of close to $2 billion.

[57] Further details on each of these examples, as well as additional case study material, is included in Appendix One.

- ResMed: Dr Peter Farrell formed the ResMed group of companies to commercialise technology developed by Dr Sullivan at the University of Sydney in the 1980s. The ARC's predecessor organisation provided funding support for this research. Sullivan and his colleagues invented a method of treatment of a major sleep disorder, obstructive sleep apnoea. ResMed is now a publicly listed company, valued at $2.5 billion in 2001 with 850 employees (over 400 in Australia). ResMed revenues exceeded $400 million in 2002-03 and revenues are growing at 25 per cent per annum. The total size of the 'sleep industry', which it helped create, was valued at $1 billion in 2001 worldwide, and growing at 20 per cent per year.

- Ventracor: Ventracor is a publicly listed company formed to develop a rotary heart pump, initially developed by researchers at the University if Technology, Sydney. The ARC provided funding of $453,000 between 1997 and 1999. The rotary heart pump is at the stage of human trials. As yet Ventracor has not turned a profit on the technology. The market potential is estimated to be between US$7.5 billion and US$12 billion annually. Ventracor is listed on the ASX and had a market capitalisation as at April 16th 2003 of $200 million and was included in the S&P/ASX index on April 1st 2003.

- Biosignal Pty Ltd: Biosignal is a company set up to commercialise technology developed at UNSW. The technology will apply to many products. Total ARC funding over 9 years to 2003 is estimated at $1.1 million. Biosignal Pty Ltd is currently in collaboration with a number of international companies developing numerous applications of this technology. These products are in the development phase, with product-related revenues anticipated by 2005. The projected revenue from commercialisation in 2005 is $2.5 million, rising to $63.8 million by 2008. The company is currently generating $1 million per year in collaborative development income.

- Proteome Systems Limited (PSL): PSL is a private company developed by Professor Keith Williams, with technology developed at Macquarie University. The technology relates to manipulation of amino acids in proteins. Proteomics enables enzymes and other proteins to be analysed using high-speed automated equipment. The ARC provided $257,000 in funding in the mid to late 1990s. PSL employs 100 staff in Sydney and Boston. Turnover in the 2002-03 financial year is forecast to reach $15 million, up from $7.7 million in 2001-02, with the unlisted company valued at $400 million. The global market for the proteomics sector in 2000 was estimated at $US 1 billion, growing to nearly US$6 billion in 2005.

- Advanced Powder Technologies (APT): Development of a new low-cost process for the manufacture of a wide range of ultra-fine nanoscale powders. The ARC provided $250,000 from 1990 to 1999. APT has entered into a $12 million partnership with Samsung Corning. Projected to capture 15% of the estimated $1 billion world market for NanoPowders.

- Radiata: Radiata developed groundbreaking chip technology for enabling very high-speed communication over wireless local area computer networks. The ARC provided $529,000 in funding between 1994 and 1999. The technology was sold to Cisco Systems in 2000 for $US295 million.

- First Nucleotide Change (FNC): FNC is biotechnology which helps in the detection of genetic diseases and traits. The ARC has provided $742,000 in funding since 1990. This technology was subsequently sold to US biotechnology company Affymetrix, for an upfront fee and on-going licence payment. The value of the sale to date is estimated to be a minimum of $4 million.

- Securities Industry Research Centre: SIRCA is a university-based, industry-sponsored financial markets research centre which identifies high-priority industry problems, as well as generating innovative software products. The ARC has provided $5 million in funding since 1994. The development of expertise in research infrastructure resources has led to the creation of leading-edge software which to date has been sold to a number of international clients, including the Russian Central Bank, the Moscow Inter-bank Currency Exchange, the Jakarta Stock Exchange, the Hong Kong Stock Exchange, the Oslo Stock Exchange and the Hong Kong Securities and Futures Commission. The sale of software attracts some $3-$5 million in export income each year.

- IATIA: Quantitative Phase Microscopy (QPm) technology was developed by University of Melbourne physicist and ARC Federation Fellow, Professor Keith Nugent and his team with ARC funding of approximately $765,000. The technology adds a new dimension to scientific research by allowing users to make quantitative measurements. QPm has given researchers a new tool, providing increased capacity for new scientific discovery. In 2000, a new company, IATIA, was floated to commercialise QPm technology. Using an ARC linkage grant, researchers are now studying new ways in which the QPm can be applied. Since publicly listing, IATIA has launched two new products, QPe and QPt. In 2002 the company had a market capitalisation of $30 million and 30 employees.

The sale of ARC funding-based technology companies has exceeded $500 million in 2002 dollars, while the remaining Australia-based operating companies generate revenue in excess of $700 million per annum. The market valuation of these companies, reflecting the risk-adjusted net present value of the expected future profit flows from these companies, exceeds $4 billion. The cumulative direct impact of these companies' activities on GDP would, on a conservative estimate, have exceeded $1 billion in 2002.

In order to estimate the rate of return on ARC investment that the activities of such companies represents, it is necessary to determine the extent to which the success of these companies can be attributed to the ARC. Clearly the ARC provided funding at the crucial early stage of the development of the technology that these companies have been built upon. However, much larger levels of capital have subsequently been provided from other sources in order to allow these technologies to be commercialised. Attribution of benefits to the ARC requires balancing of the key role it played in the development of the technology versus the relatively small overall level of its contribution to the total costs associated with the successful commercialisation of the technologies.

One approach to determining the relative significance of the ARC's role is to look at what occurs, in terms of equity holdings, during the expansion of a 'typical' start-up technology company[58]. Typically, the first seed investor will inject a relatively small amount of funds in return for a relatively large share of equity when compared to later investors. This is because the risks associated with early investment are much higher than for later investment. Table 6.1 sets out a hypothetical case of how equity holdings (a proxy for responsibility for final outcomes) may change as a company expands and its valuation increases as it grows and risk falls.

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[58] There is of course no 'typical' start-up technology company. Each company follows a unique growth path, with its own unique path of investment raising and equity dilution. However, the example set out below appears to be a 'reasonable' projection of the type of investment and equity dilution pathways that a successful start-up technology company might follow.

Table 6.1

EVOLUTION OF EQUITY HOLDINGS IN A TECHNOLOGY START-UP COMPANY

	Initial investment by seed funder	Investment by early stage venture capitalist	Investment by later stage venture capitalist	Public share issue
	$0.8 million	**$5 million**	**$10 million**	**$30 million**
Valuation of company	$1 million	$10 million	$20 million	$60 million
Equity held by inventor (who provides no monetary investment)	20%	10%	5%	2.5%
Equity held by seed funder	**80%**	**40%**	**20%**	**10%**
Equity held by early stage venture capitalist		50%	25%	12.5%
Equity held by later stage venture capitalist			50%	25%
Equity held by public investors				50%

In this hypothetical case, while the seed funder contributed under 2 per cent of the total investment funds that have gone into the company, the seed funder actually owns 10 per cent of the mature company. This is because the seed investor provided funding at a riskier stage in the company's development, when the cost of equity was consequently lower than that faced by later-stage investors. If ownership is a proxy for 'degree of impact' on final outcomes, then the seed funder in this case would be attributed 10 per cent of the responsibility for the final outcome achieved by the company.

The ARC, by providing early-stage funding for risky research can be seen to have played the role of the seed funder in the case of the companies that have been based on the research that the ARC-funded. It is therefore arguably reasonable for the ARC to claim approximately 10 per cent of the 'credit' for the subsequent contribution to GDP made by these companies. It should also be noted that, in many cases, the relevant products may never have been developed in Australia without the ARC funding.

Rate of return calculation

If the activities of companies that have directly commercialised ARC-funded research contribute around $1 billion to GDP, and the ARC is on average 10 per cent responsible for the success of these companies, the commercialisation of ARC-funded research can be seen to have contributed $100 million to GDP in 2002.

Assuming that the share of these companies' activities within GDP remains constant over the short to medium term (a conservative assumption given these are still rapidly growing companies) and that GDP grows at same rate as the government bond rate (which is the deflator used for net present value calculations), the permanent increase in GDP in 2002 dollars remains the same as its actual contribution to GDP in 2002.

This $100 million permanent increase in GDP represents the payoff (through direct commercialisation) to perhaps 20 years of ARC funding activities prior to 2000. The value of this funding in 2002 dollars totals approximately $3.5 billion. The social rate of return on this investment is therefore just under 3 per cent. It is important to note that this calculation of commercialisation returns is likely to be very conservative. The commercialisation benefits from ARC research funded in the 1990s are likely to be only just emerging or indeed may still be some years off.

Given the time taken for start-up companies to further refine and then bring technology-based products to market, it is reasonable to assume an average time lag for the commencement of benefits (through direct commercialisation) from any given year's funding is likely to be around 10 years.

6.3 Benefits from improving the skills base

In order to develop an estimate of the impact of the contribution of ARC funding to improving the national skills base we have reviewed available literature surrounding the impact of skills formation on economic performance. This includes identifying the additional value placed on the labour of those with postgraduate qualifications (reflected in higher wages and lower rates of unemployment) and considering the extent to which these outcomes reflect higher productivity associated with such workers.

Key identified ARC contributions

Through funding students directly and through funding research projects and facilities that improve the quality of students' education, the ARC makes an important contribution to improving the Australian skills base. Through estimating the contribution to the education of students made by ARC funding, it is possible to then calculate the contribution of ARC funding to the economic benefits associated with the skills of those acquiring postgraduate qualifications in Australia.

The Australian Postgraduate Research Awards (Industry) scheme was introduced in 1990. Through this program the ARC provides funding for students to undertake postgraduate research studies. Table 6.2 sets out the number of new awards commencing since this program commenced (funding generally continues for at least three years following commencement). The number of awards commencing each year has shown strong growth since the commencement of the program.

Table 6.2

NUMBER OF APA(I)S AWARDED BY YEAR

	Year												
	90	91	92	93	94	95	96	97	98	99	00	01	02
Number of APA(I)	60	80	102	125	125	125	151	205	232	288	334	350	389

Source: ARC internal data

Between 1990 and 2002 (as Table 6.2 shows) 2,566 APA(I)'s have been granted. This figure represents the number of students whose postgraduate studies have been directly funded by the ARC through this program. It does not include the far greater number of students that have benefited less directly from ARC funding activities.

The ARC contributes to the quality of the higher education sector through a number of ways, including providing: direct funding for students; funding for improving research training; funding improved research facilities; funding for research projects that involve numerous students; and funding to attract and retain leading academics within the system. When the variety of ARC funding activities is considered, it becomes evident that there are five categories of students who benefit to some degree from the funding activities of the ARC, namely:

- research post-graduate students directly funded by the ARC through APA(I)'s and through the funding of stipends as part of project funding;

- research post-graduate students who work on projects or facilities funded by the ARC;
- research post-graduate students who, while not directly involved in ARC-funded projects, benefit from the generally higher-quality research infrastructure and environment within the Australian higher education sector due to ARC funding; and
- non-research post-graduates whose educational experience is improved by the fact that the Australian higher education sector has a strong research component[59] – to which the ARC is an important contributor; and
- under-graduate students whose educational experience is improved by the fact that the Australian higher education sector has a strong research component – to which the ARC is an important contributor.

Obviously, the strength of the links between the activities of the ARC and the skills acquired by these groups of students differs.

Rate of return calculation

A snapshot study of the ARC's contribution to students' education in 2002 allows for the calculation of the direct skills formation benefits associated with ARC funding.

While judgements regarding the strength of the links between the ARC and the skills acquisition of different categories of students are of course subjective, it would appear reasonable to assume that for:

- directly funded research post-graduates – given that the ARC provides direct financial support to the student and that the students work on ARC-funded projects, the ARC is at least 75 per cent responsible for funding the skill formation of these students;
- research post-graduate students involved in ARC-funded projects – given that the ARC funding allows for the attraction and retention of leading researchers in the Australian higher education sector and that its funding of particular projects and facilities focuses on leading-edge research, the ARC is at least 20 per cent responsible for funding the skill formation of these students;
- other research post-graduate students – given that the ARC invests strongly in improving the overall quality of research training in Australia, and provides around 10 per cent of total research funding within the higher education sector, it is reasonable to assume that the ARC is at least 10 per cent responsible for funding the skills formation of these students;
- non-research post-graduates and under-graduate students – given that the quality of research within the higher education system is linked to (particularly) the quality of post-graduate coursework teaching within the system, and that the ARC is a major contributor to the quality of research in the Australian higher education system, it is reasonable to assume that the ARC is at least 2 per cent responsible for funding the skills formation of these students; and

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[59] While there is ongoing debate regarding the strength of the link between the quality of research and the quality of teaching in the higher education sector (whether due to their both occurring in any given institution, or due to links between research and teaching focussed institutions) there is little doubt that maintaining the quality of teaching does require access to the latest knowledge generated by research in the field being taught.

- under-graduate students – given that the quality of research within the higher education system is linked (albeit less strongly than for post-graduate coursework teaching) to the quality of under-graduate teaching within the system, and that the ARC is a major contributor to the quality of research in the Australian higher education system, it is reasonable to assume that the ARC is at least 0.5 per cent responsible for funding the skills formation of these students.

In order to calculate the direct economic value of the skills formation that the ARC has contributed to, it is necessary to consider the wage premium paid in Australia for different levels of qualifications and also the extent to which the wage premium reflects the increased productivity associated with people with these qualifications.

In Australia, the average full-time wage for all post-graduate degree holders is $6,600 per annum higher than that for under-graduate degree holders while the average full-time wage for graduate degree holders is $19,300 per annum higher than that for those holding only Year 12 qualifications[60].

These wage premiums do not however fully reflect the likely productivity premium associated with these qualifications. The Productivity Commission has found that in Australia approximately half of output is returned to labour while half is returned to capital[61]. This suggests that the output premium for post-graduate degree holders versus under-graduate degree holders is $13,200 per annum while it is $38,600 for under-graduate degree holders versus year 12 completers.

A further complicating factor in calculating the benefits from skill formation associated with ARC funding is that the productivity premium associated with different levels of qualification may result from a combination of both the additional skills held by those with these qualifications and the personal attributes associated with those that gain such qualifications. It is possible that those who gain post-graduate qualifications on average have higher intellectual capacity than those who do not, and that part of the productivity premium associated with such qualification holders relates to such personal ability rather than the skills acquired through their studies. In order to allow for this possibility, in calculating the productivity premium associated with different qualification levels, only two-thirds of the premium has been assumed to be due to skills acquisition rather than natural ability differences[62].

Based on the above analysis, calculations of the (near) permanent increase in GDP due to the ARC's contribution to skills formation in 2002 can be formulated as follows:

- $13,200 x 0.67 x 389 APA(I) students[63] x 75% ARC contribution = $2.6 million permanent increase in output in real (2002 dollars) terms.

- $13,200 x 0.67 x 1,000 post-graduate completers involved in ARC projects[64] x 25% ARC contribution = $2.2 million permanent increase in output in real terms.

[60] ABS, 4230.0, (2003)

[61] Parnham, D., (2000)

[62] This is a conservative assumption. Other studies, cited in Johnson, D. and Wilkins, R., (2003), pg 7, have found that around 80 per cent of the wage advantage of graduates over non-graduates is derived from the effects of higher education and only 20 per cent is due to natural ability.

[63] ARC data

[64] ARC internal figures

- $13,200 x 0.67 x 4,100 other research post-graduate completers not directly involved in ARC projects[65] x 10% ARC contribution = $3.6 million permanent increase in output in real terms.
- $13,200 x 0.67 x 56,500 non-research post-graduate completers[66] x 2% ARC contribution = $10.0 million permanent increase in output in real terms.
- $38,600 x 0.67 x 125,000 under-graduate degree completers[67] x 0.5% ARC contribution = $16.1 million permanent increase in output in real terms

These average output premiums are likely to stay reasonably constant in real terms over the thirty-year average working life of these groups of qualification holders. Given that these benefits continue to accrue throughout the average working life of 30 years, for the purpose of calculating the social rate of return we assume that the increase in GDP due to each cohort of students is permanent. This makes very little difference to the overall calculation due to the minimal difference in the net present value of a 30 year increase in GDP versus permanent increase, given the very high deflation rate (due to great uncertainty regarding any projected benefits accruing more than 30 years in the future) associated with benefits beyond the 30 year period.

The total permanent output premium for the 2002 student cohort is therefore $34.5 million[68]. Therefore, given that total ARC funding was $272 million for 2002, the direct social rate of return from skills formation due to ARC funding can be estimated at approximately 12.5 per cent. However, the benefits from ARC funding for each new cohort of students will generally not commence until four years after funding is made, given the time associated with completion of studies.

Caveats relating to rate of return calculation

Clearly a number of simplifying assumptions are implicit in the above analysis. Some will bias the rate of return estimate to underestimation while others would have a bias towards overestimation. Three such issues not factored into the calculations include:

1. Given that ARC-directly-funded students receive funding through a competitive process, they may be better than the average post-graduate students and hence have a higher wage/productivity premium than the average for post-graduates. For instance, in relation to the mining sector in one state, over 80 per cent of senior level executives were former graduates of an ARC key research centre[69]. Omission of this factor in our calculations results in a bias towards underestimation of benefits.

2. Our analysis doesn't consider the actual employment history of students. Given that not all graduates will in fact have a thirty-year working life in Australia, and indeed some may never work in Australia (although some will work longer than 30 years), failure to account for this may provide some bias in our analysis towards overestimation of benefits.

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[65] DEST, (2003) combined with ARC data

[66] DEST, (2003)

[67] DEST, (2003)

[68] In 2002 the ARC has not contributed to the full three to four year cost of the 2002 graduators' education, but rather just to the final year of their studies. However, given that the ARC in 2002 is also contributing by funding a year of the studies of the subsequent 2003, 2004 and 2005 graduating classes, the number of graduates in a given year is a reasonable proxy for the total number of graduates that the ARC funding contributes to per year.

[69] Turpin et al, (1999)

3. We do not calculate the welfare cost savings and increased tax revenue associated with those people who obtain post-graduate and under-graduate qualifications. Failure to factor in these impacts may lead to a bias towards underestimation of the benefits from such qualifications.

Within the time constraints associated with this study it has not been possible to factor in all possible complicating factors such as those above. However, given the conflicting impacts of these factors, it is unlikely that overall such factors would substantively impact on the level of benefits associated with ARC-linked skills formation.

6.4 Benefits from improved access to international research

Australia as a relatively small country contributes about 2 per cent of the world stock of knowledge, which is considerably beyond its share of world population or world GDP. The important point is that Australia, especially through conducting world-class cutting-edge research supported by bodies like the ARC, is able to gain a place at the world research table and to access global research networks which can produce significant benefits to the economy and the community.

A number of international studies[70] have identified that growth in the international stock of knowledge has an impact on productivity growth not only of the countries in which the research is conducted but also of other countries, i.e., significant international spillovers are associated with research. However, these studies also indicate that the extent to which a country benefits from international knowledge formation depends on factors such as the availability of a workforce appropriately skilled to understand and adapt this knowledge and the extent to which the country is linked into international knowledge networks. The 'free-rider' strategy is simply not viable in the long term.

As was discussed in Chapter 4, there are a number of ways that a country can benefit from research conducted in other countries. Companies can utilise productivity-improving products and processes developed overseas (for instance IT tools), buy patents, licences and know-how from foreign firms, they can hire foreign engineers and scientists, reverse engineer products available overseas, read international scientific and technical literature or have direct contacts with foreign engineers and scientists at conferences.

The ARC contributes both to Australia's ability to access foreign R&D and our ability to absorb and adapt foreign R&D. It indirectly improves Australian industry's ability to absorb and adapt foreign R&D due to its important role in building the research skills base in Australia.

To develop an estimate of the direct contribution of the ARC to the benefits associated with international knowledge creation it is necessary to consider its role in developing direct linkages to international research networks and thus improving access to international knowledge. Using available data on ARC projects involving international collaborations, we have attempted to measure the value of the foreign research to which ARC projects have given Australia improved access.

[70] In particular a recent OECD study provides valuable data in this area. OECD (2001), STI Working Paper 2001/3, *R&D and Productivity Growth: Panel Data Analysis of 16 OECD Countries*

Key identified ARC contributions

In the 1999-00 ARC annual report the ARC estimated that 40 per cent of large research grant projects involved international collaborations. In 2002 large research grants (Discovery) totalled almost $200 million. Therefore it is likely that $80 million worth of grants had some international collaboration aspect attached to them. In 2002 the ARC also provided 66 new international linkage grants totalling $2.7 million.

Through providing funding for projects that involve international research collaboration, the ARC is in effect buying access for Australia to the total value of the research funding that is going into these international collaborative projects.

In awarding grants that have an international collaboration, a key selection criterion is that at least a 1:1 ratio is achieved in terms of international and Australian dollars contributed to the collaborative project. However, in a number of cases the ratio of international to Australian dollars clearly exceeds this 1:1 ratio.

In these cases, Australia accesses facilities that have capital and operating costs far larger than Australia would be able to support by itself. For "big science" this is really the only way for Australia to participate in such research fields. Indeed, there are now almost no major international "big science" facilities that are built by a single country. The reasons for collaboration have to do with cost-sharing, risk-sharing, and maximising the human capital that is applied to use the facility. Small countries such as Australia tend to get high levels of funding leverage from joining "big science" projects, since the researchers often have a standing in the project that is significantly larger than the cash paid.

Three examples of where ARC funding for collaborative research projects provides high international funding leverage benefits are:

- the Gemini project - the cost of the centre over 10 years is split about 50/50 between capital and operating costs. The capital value is $US193.2M and the annual operating cost is about $US24.3M. Australia contributes about 5 per cent to these costs and in return gains 5 per cent of the usage time at the facility. This does not imply, however, that Australia simply gets access of equivalent value to what it would receive if it had spent its contribution instead on building a smaller facility to which it had 100 per cent access.

  This is because Australia’s contribution to Gemini would allow for the purchase and operation (including 100 per cent access) of only one telescope of approximately 2.5m diameter, which is not of equivalent research value to having 5 per cent access to the Gemini telescopes which have a combined diameter of 16 metres. This is because the Gemini telescopes are in fact 260 times more powerful than a 2.5 diameter telescope[71]. Having 5 per cent access to Gemini therefore gains Australia access to 13 times more telescope power relative to that which we would have via 100 per cent access to a smaller facility. This would imply that a value for money leverage of 13:1 has been achieved through participation in Gemini. However, it should also be stressed that for technical reasons there are actually very few scientific projects that could actually be done at all by using more time on a smaller telescope.

[71] The main performance measures of a large telescope are their area (to collect light) and diameter (to resolve small objects) so that performance scales as the cube of the of the diameter. Thus, Australia's share converted to 100 per cent of a smaller facility would fund a telescope that is (16/2.5)^3=260 less powerful than Gemini.

- the ISIS facility - ISIS is the world's (currently) most powerful neutron spallation source, located at the Rutherford Laboratories in the UK. Australian access to the facility is based on an annual payment of $A400,000, representing approximately 1 per cent of the operating cost of the facility. Projects conducted at the facility are selected on scientific merit and Australian researchers as a result secure approximately 3 per cent of the time available for use of the facility. This suggests a usage multiplier of 3 relative to Australian contributions to the cost of the facilities, i.e. a leverage ratio of 3:1. It is important to note, however, that without the access to ISIS the research could not be done at all as A$400,000 would not be adequate to provide any useful alternative facility.
- the Large Hadron Collider (LHC)/Atlas detector facility - there is only one LHC/Atlas, and it is uniquely capable of performing the experiments for which it is designed. Australia contributes 1.1 per cent of the cost of this facility. The research program is defined by the consortium (and not by selection on scientific merit, as with ISIS) and Australian participants in LHC/Atlas have the right to be named on all publications from the facility. Australian participants therefore gain access to 100 per cent of the research outcomes from the facility, despite only contributing 1.1 per cent of the facility’s costs. Therefore, a leverage ratio of 91:1 occurs in this instance.

Rate of return calculation

The ARC estimates that, for every $1 of funding it provides for Australian researchers to participate in international research projects, Australia gains access to on average at least an additional $2.50 in internationally funded research or research facilities.

Therefore, given that in 2002 around $80 million of ARC money was used to ‘buy access’ to international research funding, the total value of international funding that was accessed due to the ARC would be in excess of $200 million in 2002.

While the theoretical analysis in section 5 suggested that the rate of return on basic research may be around 50 per cent, given that the internationally funded research that the ARC provides access to is not as closely linked to the Australian innovation system, the social rate of return realised through knowledge use, commercialisation and improvements to policy making from this international research would be expected to be lower than that obtained from domestic research funding. Also, the international research does not generate skills formation benefits in the way that domestic research funding does.

If the assumption is made that the social rate of return from knowledge use, commercialisation and improvements to policy making is only half that associated with domestic research, and that there are fewer skills formation benefits flowing from access to international research, the social rate of return associated with international research funding would be around 10 per cent. This would still suggest that, due to ARC funding of international collaborative research projects in 2002 (which facilitated access to around $200 million of international research), Australia generates a $20 million increase in GDP. Given ARC research funding of $272 million in 2002, this suggests an overall social rate of return from international collaboration of around 7.5 per cent. However, there will be a time lag between access to international R&D and the reaping of economic benefits from this research. An average time lag of eight years would appear reasonable given the average lags associated with benefits derived from Australian research.

6.5 Benefits from improving policy making

The policy-making process in a modern democracy is a complex amalgam of many different strands, involving inputs from interest groups, independent researchers, the media, political parties and so on. Nevertheless, as John Maynard Keynes noted many years ago, the power of ideas to influence policy development for good or ill should not be underestimated. Building a broad consensus, which is often a necessary condition for bringing about major change, usually requires a strong basis in evidence and analysis.

A significant potential benefit of research in the range of matters covered by the ARC is that it can be an important, and sometimes decisively important, input into the policy development process in important cases. Given the complexity of the policy development process, precise attribution of cause and effect is very difficult. But there are significant areas of policy development in the recent past where some degree of attribution to the research funded by the ARC is clearly warranted.

Beyond the difficulties associated with attribution, a further difficulty surrounds credible quantification of the benefits associated with particular policy decisions.

Key identified ARC contributions

A major area of policy development for which credible estimates of benefits have been made in recent years concerns microeconomic policy. The Productivity Commission has argued that microeconomic reform was responsible for 0.8 percentage points of the 1.1 percentage point increase in MFP growth rates in Australia for the period 1993-94 to 1999-2000 (when compared to the MFP growth rate between 1988-89 to 1993-94 of 0.7 percentage points)[72]. This suggests that the microeconomic policy reform of the 1980s and 1990s was responsible for approximately 45 per cent of MFP growth during the 1990s.

Microeconomic policy is by no means the only area where ARC-funded research may have been a contributor to significant economic impacts. However, given the difficulties associated with estimating the size of benefits associated with other policy decisions (which could also include negative returns in the case of poor policy decisions) and with determining the relative significance of the drivers of implementation of these policy changes, the quantitative assessment of benefits in this area has been limited in this study to the policy area of microeconomic reform.

The ARC continues to provide considerable funding for economics research, with almost $5 million of new grants in this field being awarded in 2002. ARC funding has played an important role in research that has contributed to economic policy reform in Australia. Consideration (see Box 6.1) of the role of ARC funding in supporting the continuing development of significant general equilibrium models of the Australian economy illustrates this point.

[72] Parnham, D., (2002a)

Box 6.1

ARC SUPPORT FOR THE ORANI AND MONASH ECONOMIC MODELS

The Centre of Policy Studies (CoPS) is part of the Faculty of Business and Economics at Monash University. It currently employs 13 academics and 4 support staff. Its annual budget is about $1.8 million of which about $1.4 million comes from sources outside the University.

The research team at CoPS has been responsible for the development of the ORANI and MONASH models and the GEMPACK software. ORANI, MONASH and their derivatives have been used for the last 25 years by numerous people to address a wide range of important economic policy issues. These include the effects of changes in tariffs, taxes, technologies, competition policy, world commodity prices, industrial relations policy, resource policy and wage policy. Results from the models are used regularly by State governments, the Commonwealth government, business organisations and university academics. On several occasions ORANI and MONASH results have been debated in the Commonwealth and State parliaments. The GEMPACK software is used at 300 sites around the world to compute solutions of economic models for about 50 countries.

The CoPS team has a continuous history going back to the formulation in 1975 of the IMPACT Project in the Industries Assistance Commission (IAC). The team has moved between the IAC and 3 of Melbourne's universities. Its present stint at MONASH started in 1991. Over this long history the team has relied on a variety of funding sources. Initially, all of the funds were supplied by the Commonwealth government through the IAC. However since 1991, when the team arrived at Monash, the bulk of its funding has come from contract research for governments and businesses.

In these circumstances, the ARC has played a significant role. Between 1991 and 2002, CoPS received about $700,000 from the ARC in Discovery grants (formerly known as Large grants), Small grants, and SPIRT grants. Although this financial contribution has been relatively small (less than 5 per cent of CoPS funding), it has been important.

The ARC has funded development work. This includes theoretical specification of economic models, the collection and analysis of data, the estimation of parameters, and the creation of software for solving and interrogating models. It is extremely difficult to finance development work through contract research. The demands of clients are usually too specific and their time lines are too short. Without ARC and university funding it would not have been possible for CoPS to continue to develop and maintain economic models. Thus, it would not have been possible for CoPS to continue to provide a steady stream of valuable services to the Australian public and private sectors.

Source: Peter Dixon, CoPS

Through consideration of a number of case studies we can conservatively estimate the contribution of ARC-funded research to microeconomic reforms instituted in Australia. Then, using Productivity Commission estimates of the economic impacts of these reforms, an estimate of the contribution of ARC funding to the economic benefits associated with microeconomic reform in Australia can be made.

It should be noted that ARC research funding is also likely to have had important impacts in other areas of policy, such as environmental policy and the law. For instance:

- ARC-funded research in environmental law by Professor David Farrier resulted in significant input into the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999*. As Director of the Institute for Conservation Biology and Law at the University of Wollongong, Professor Farrier investigates the role of different levels of government in nature conservation, and he has contributed to the development of policy instruments for biodiversity conservation and the implementation of international nature conservation conventions in Australia.
- The ARC-supported Australasian Legal Information Institute (AustLII) provides free on-line access to Australian and international legal material—in effect, a public law library on the Internet. AustLII publishes public legal information—that is, primary legal materials (legislation, treaties and decisions of courts and tribunals) and secondary legal materials created by public bodies for purposes of public access (law reform and royal commission reports for example). By maximising access to the law, AustLII supports the rule of law and transparent legal systems that enhance Australia's economic and global competitiveness.

Unfortunately, quantification of benefits in such policy areas is extremely difficult and has not been possible within the time and data constraints of this study. Therefore, the rate of return calculation below focuses only on the returns associated with the contribution of ARC-funded research to microeconomic reform.

Rate of return calculation – contribution to microeconomic reform

According to the Productivity Commission, microeconomic reform contributed 0.8 percentage points of MFP growth from 1993-94 to 1999-00. Given that GDP in 1993-94 was $510 billion (in 2000-01 dollars)[73], the cumulative impact of this increase in the MFP growth rate over the following six years is that GDP was approximately $73.3 billion (in 2000-01 dollars) higher at the end of this period than it would have been without the impact of microeconomic reform policies[74].

Attribution of the benefits from microeconomic reform is necessarily a subjective task. It would appear that three key groups played an important role in the development and implementation of microeconomic reform in Australia over the 1980s and 1990s, with each group being able to rightly claim some attribution of the subsequent benefits from reform. Firstly, a theoretical case for implementation of microeconomic reform was required. Secondly, there needed to be a group or groups (such as think tanks and business peak lobby groups) to advocate the case for the introduction of reform. Thirdly, politicians (and their advisers) needed to accept that reform was needed if Australia was to meet the imperative to become more internationally competitive and to then design and implement the reforms.

While it is true that the actions of the first and second groups were a necessary condition for microeconomic reform to occur, it is also the case that their actions were not sufficient to cause reform to be implemented. Many policy options have a theoretical justification and advocates but nevertheless are not implemented. The sufficient condition for reform is that politicians are willing to implement change. It therefore seems reasonable to assign the clear majority of attribution for microeconomic reform to politicians. The respective roles of theoreticians and advocates appear to perhaps be on a par with each other in regards to prompting reform. Without solid theoretical justification advocacy rarely succeeds, while, in the absence of strong advocacy, theory rarely enters the mainstream public policy debate.

We have therefore, for the purposes of attribution the benefits from microeconomic reform, adopted the following split between the three key groups:

- 75 per cent assigned to ‘politicians’;
- 12.5 per cent to ‘advocates’; and
- 12.5 per cent to ‘theoreticians’.

These weighting are of course subjective and open to debate. However, they would appear to be ‘reasonable’.

[73] ABS, 5204.0, (2002b)

[74] This figure is generated by subtracting 0.8 percentage points from the actual GDP growth that occurred for each of the years during the period 1993/94 to 1999/2000. Actual GDP in 1999/2000 was $657.8 billion, whereas, if GDP growth had been 0.8 percentage points lower for each year since 1993/94, by 1999/2000 GDP would only have reached $584.5 billion.

Of interest in determining the role of the ARC funding of research in economic reform, the group that requires further analysis is that of ‘theoreticians’. The theory that underpinned microeconomic reform in Australia came from two key sources:

- fundamental economic theory – which was largely developed overseas;
- the application of theory to the Australian context – which involved both refinement of broad theory to the Australian context and the development of models of the Australian economy which were used to demonstrate the benefits available from microeconomic reform in the Australian context.

Both these activities were necessary for the development of a theoretical justification for microeconomic reform in Australia, so we have assigned equal weighting to these functions. Domestic ‘theoreticians’ can therefore be seen to be around 6 per cent responsible for microeconomic reforms implemented in Australia. Key theoreticians in Australia that worked to apply economic theory to the Australian context included:

- the Productivity Commission, and its predecessor the Industry Commission;
- the Treasury; and
- academic economists and econometricians – whose work was often utilised by both the Treasury and the Productivity Commission in their analysis.

Again, based on subjective judgement, it seems reasonable to assign at least 15 per cent to the work of the third group – meaning that Australian academic economists and econometricians can be attributed almost 1 per cent of the responsibility for microeconomic reform in Australia. In order to determine the contribution of ARC-funded research to microeconomic reform, it is therefore necessary to identify the importance of ARC funding to the work of academic economists and econometricians in the field of microeconomic reform.

Consideration of the extent to which the ARC funds economic research, and analysis of some case studies relating to ARC funding of economic research, suggest that the ARC did in fact play an important role in supporting the outputs from academic economists and theoreticians that contributed to the theoretical justification for microeconomic reform.

In addition to the example (see Box 6.1) of funding provided to support the development of econometric models, another example of the ARC’s funding economics research that has contributed to microeconomic reform is the policy influencing work of the Securities Industry Research Centre of Asia-Pacific (SIRCA). Details are set out in Box 6.2 below.

Box 6.2

ARC CONTRIBUTION TO REDUCED TRANSACTION TAXES

SIRCA is a university-based, industry-sponsored financial markets research centre which identifies high-priority industry problems, as well as generating innovative software products.

In addition to a direct commercialisation return from the sale of software developed by the centre, through the publication of over 50 research papers, intellectual property developed by the centre has found a 'route to use' that didn't involve direct commercialisation. SIRCA is a not-for-profit company limited by guarantee and governed by a board comprising senior representatives from member universities, commercial organisations, government representatives and industry associations.

Aided by almost $5 million of ARC funding since 1994, the centre's research has involved every sector of the Australian Securities Market, leading to various technological innovations and directly improving Australia's market efficiency. The direct impact of the research on market efficiency is best illustrated by the work of Professors Aitken and Swan on transaction taxes. Their modelling of the relationship between trading activity and transaction costs on behalf of the ASX helped convince State Governments in Australia to halve stamp duty. The net effect was a large increase in the value of securities and a 20 per cent reduction in the other costs of trading.

Source: SIRCA, ARC

Overall, in 2002 approximately 1.4 per cent, totalling almost $5 million, of all new ARC grants were allocated to the field of economics research. A similar proportion of ARC grants were also allocated to economic research in the 1980s and 1990s. Given the extent of ARC support for economic research, 25 per cent would appear to provide a conservative estimate of the significance of ARC-funded research within the relevant academic economic research output of the 1980s and 1990s. This suggests that the ARC research funding was potentially 0.25 per cent responsible for the implementation of microeconomic reform in Australia in the 1980s and 1990s. In other words, 99.75 per cent of the credit for micro-economic reform is *not* being attributed to the ARC.

If ARC-funded economic research was 0.25 per cent responsible for the benefits accrued (from microeconomic policy changes) between 1993-94 and 1999-2000, then it can be argued that ARC-funded economic research resulted in GDP being $183 million higher in 1999-2000 than it would otherwise have been.

ARC funding from 1979-80 to 1998-1999 - the 20 year period where the ARC may have funded research that had some impact on the microeconomic reform policies which generated the benefits over the 1993-94 to 1999-2000 period - totalled $3.03 billion (in 2000-01 dollars). The permanent increase in GDP of $183 million (as at 1999-2000) from microeconomic reform that can be attributed to the ARC research funding represents a 6 per cent social rate of return on all ARC funding over the preceding twenty-year period.

A time lag is again involved in the translation of ARC-funded research into policy and in term for the translation of policy changes into economic benefits. A reasonable estimate of such time lags may be in the order of eight years.

Again it should be noted that only benefits from policy making in the area of microeconomic reform has been included in the quantification of benefits accruing through improved policy making. Other areas of potential benefits, such as legal reform, education policy and so on have not been able to be quantified within the constraints of this study.

6.6 Health, environmental, social and cultural benefits

The health, environmental, social and cultural benefits generated by public research and development activities are likely to be highly significant to the Australian community. For example, major benefits would accrue from better health outcomes made possible by research in terms of improving the quality of life – there would also be direct economic benefits in terms of improved labour force productivity and reduced health expenditures. Major benefits also accrue to the environment through research – there would also be direct economic benefits in terms of sustainable agricultural production leading to higher long-term agricultural productivity and in some cases the ability of rural and tourism land uses to better co-exist. Research in the humanities could be expected to contribute substantial cultural and social benefits, such as better equipping society to embrace and adapt to change. There could also be significant economic benefits from research in the social sciences - one element of which (the contribution to better policy outcomes in the area of economics) was considered in Section 6.5.

However, attempting to quantify health, environmental, social and cultural benefits would be an extremely complex task and such an exercise is not possible within the time constraints of this project. Therefore our analysis of the benefits in these areas generated by ARC research funding is primarily of a qualitative rather than quantitative nature.

The ARC provides considerable funding for research activities that are likely to generate health, environmental and cultural benefits for Australia. For example, in relation to the five-year pipeline of funding newly allocated in 2002[75]:

- approximately 5 per cent of ARC funding is for research towards promotion and maintaining good health; and
- approximately 13 per cent of ARC funding is for research towards an environmentally sustainable Australia.

While within the time constraints of this study it has not been possible to quantify the scale of environmental, health, social and cultural benefits occurring in Australia due to R&D activity or to determine the extent to which ARC-funded research contributes to such benefits, through consideration of a number of case studies of ARC-funded research projects it appears likely that ARC-funded research has generated significant benefits in each of these areas. A few examples of ARC-funded projects bringing either environmental, health, social or cultural benefits include:

- Environmental: In the early 1980s, Professor Boger, jointly funded by the ARC’s predecessor organisation and Alcoa Australia, developed a more effective red mud waste disposal system. The research yielded a revolutionary 'dry disposal' scheme. By identifying the properties of the red mud, Professor Boger made the sticky residue into a fluid by draining and stirring the residue until it became liquid enough to be pumped down a pipe to a disposal area where it would dry and resolidify. Much of the caustic waste was recovered, the dry solid stacked until it formed a stable surface, overlaid with soil and planted with grass and trees. The major environmental benefits of this new technology were decreased land use and much reduced long-term environmental liabilities. The technology has also been adopted in the nickel and gold sectors.

[75] Based on internal ARC data using RFCD codes.

- Health: The VentrAssist™ rotary blood pump, developed by Ventracor, is a significant departure from current artificial heart technology because it has removed the seals, shafts and bearings which have caused serious side effects for patients in the past, including blood damage and blood clotting. The rotary pump is operated by a small and efficient motor drive and is designed to support the work of the human left ventricle for five years or longer. There are obvious public health benefits from development of this new product. Around 44 per cent of all deaths in Australia are directly related to heart disease and about 750 Australians die from congestive heart failure every year. Many of these patients die while they are awaiting transplantation of a scarce donor heart. A major advantage of the new technology is that it can be produced at a lower cost than other pumps on the market.

- Social: AustLII, the Australasian Legal Information Institute, provides free on-line access to Australian and international legal material. With over 1.5 million searchable documents, AustLII is one of the largest sources of legal materials on the net. AustLII users include educational institutions (25%), the legal profession & business (35%), community organisations (10%), government (10%), and overseas users (20%). It provides a major database for research in Law and Justice Studies. The argument for free access to AustLII runs parallel to the arguments for publicly-funded research. For AustLII, 'maximising access to the law supports the rule of law and a transparent legal system enhances the nation's economic and global competitiveness'. The ARC has provided over $800,000 to support the development of AustLII since 1994.

- Cultural: The University of Melbourne Conservation Service commenced operation at the Ian Potter Art Conservation Centre in 1989. The Service was established in recognition of the University's need to provide for the preservation and conservation of its extensive and significant collections of cultural material. The University of Melbourne Conservation Service through the School of Fine Arts, Classical Studies and Archaeology, and the School of Physics, Earth Sciences and Chemistry has received fourteen grants from the Australian Research Council (ARC) since 1990. Central to these studies has been the investigation of artists' materials and techniques and the strengthening of art historical, cultural and scientific knowledge. This information and data are key to improved conservation practice.

Consideration of the costs associated with problems such as environmental degradation also give an indication of the scale of benefits that research into this area could potentially bring. A report to the Prime Minister's Science, Engineering and Innovation Council in 1999[76] estimated that:

- dryland salinity generates costs of at least $270 million per annum;

- soil acidification generates costs of at least $134 million per annum;

- introduced pests generate costs of between $90 and 600 million per annum; and

- overall lost agricultural production in 1991 alone due to erosion, acidification, salinisation, soil structure decline, water-repellent soils and shrub invasion was approximately $1 billion.

[76] PMSEIC, 1999

The Australian Bureau of Statistics estimates that land degradation alone now costs $1.15 billion per annum in lost agricultural production[77].

Research into the extent of environmental problems, their causes and approaches to damage limitation and reversal has the potential to reduce such costs. Even a ten per cent improvement in the above problem areas could result in increased agricultural production of over $100 million per annum.

Improved environmental management of sensitive ecosystems such as the Great Barrier Reef also has the potential to protect the future prospects of the tourism industry, an industry which the Department of Industry, Tourism and Resources predicts will be worth $30 billion per annum by 2010[78].

6.7 Summary of findings

In identifying benefits from ARC research funding in each of the six areas set out in section 3, our focus has been to quantify benefits only where there is sufficient evidence to transparently justify the measurements. This means that the quantum of benefits measured, and hence the rate of return on ARC funding, potentially underestimates the true level of benefits associated with the activities of the ARC and should be viewed as a 'lower bound' estimate of benefits.

Overall, based on analysis of measurable benefits in each of the six areas, a reasonable estimate of the measurable total social rate of return on ARC funding would be that it is around 39 per cent (while still excluding important health, environmental, social and cultural benefits from the calculation of returns). Given that not all returns have been measured it is not surprising that this estimated social rate of return is somewhat lower than the approximately 50 per cent rate of return that the 'top down' analysis in section five suggested.

[77] Quoted in PMSEIC, 2002

[78] PMSEIC, 2002

Section Seven

Modelling scenario

This chapter sets out the economic modelling scenario that has been developed using the findings from the 'bottom up' development of estimates of the impact of ARC-funded research. It then presents the main findings of the economic modelling work carried out by the Centre of Policy Studies. A full report detailing the modelling work has been attached as appendix 2 to this report.

This section also includes a discussion of the issue of whether or not ARC-funded research can be expected to generate constant returns to scale, diminishing returns or increasing returns to scale.

7.1 Overview of modelling scenario

The modelling conducted based on the findings from the 'bottom up' analysis (set out in section 6) attempts to project, based on measurements of past quantifiable rates of return on ARC funding, the economic impacts of ARC funding for the year 2003. The scenario measures the economic impacts of this one year of ARC funding over the period to 2018.

This is done by comparing two future scenarios. In the first, ARC funding occurs in 2003, in the second it is assumed that this funding does not occur. This allows a comparison of the differences in economic performance, in terms of output, consumption, investment and so on, that could be associated with the two scenarios. In order to conduct the modelling a number of assumptions have been made, namely:

- that, while the expected total social rate of return associated with ARC funding through this period is 39 per cent, benefits associated with ARC funding occur with significant time lags between when funding occurs and when various benefits flow. Therefore, for the modelling we assume the following time lags for benefits commencement:
  - in 2007, the benefits from skills formation commences;
  - in 2011, the benefits from policy formation and international knowledge commence; and
  - in 2013, the benefits from commercialisation and basic knowledge commence.
- that there are constant returns to scale on ARC funding in 2003 when compared to the rates of return associated with previous years of ARC funding (see discussion at the conclusion of this section for specific justification of this assumption); and

- that the productivity benefits from ARC funding are not felt evenly across the economy, but rather they are particularly concentrated within industries where ARC research funding is most closely related. While the returns from skills formation, improved policy making and international research access have been allocated evenly across the economy, the benefits from basic knowledge finding a 'route to use' and from direct commercialisation activities have been allocated to the broad industry categories which the case study analysis suggests have received the strongest impacts from these activities[79].

A further point worth reiterating in relation to the returns from knowledge created through ARC-funded research is that they will not in fact continue indefinitely. Knowledge tends to have a limited commercially useful life span. However, given that the benefits from knowledge do tend to continue for a reasonable period[80] and given that the current modelling exercise does not extend beyond 2018, the issue of the useful life span of knowledge is unlikely to be a significant issue.

While a number of the above assumptions still involve a degree of simplification from reality, we believe that the 'bottom up' scenarios have been designed in such a way as to generate realistic estimates for the likely cumulative economic impacts of ARC funding for the year 2003 for the period out to 2018.

Determining whether ARC funding has increasing, decreasing or constant returns to scale

In this section of the report we consider a number of modelling scenarios in regard to the impacts of ARC funding. One of the scenarios (for each of the 'top down' and 'bottom up' approaches) involves assessing what impacts would be expected from a doubling of ARC funding. It is necessary therefore to make an assumption as to whether there is likely to be increasing, decreasing or constant returns to scale associated with expanding ARC funding of research. Arguments can be made for each of these possibilities.

Increasing Returns

The argument most commonly made for the presence of increasing returns to scale from basic research is that each advance that is made provides the platform for the next and potentially more important advance in knowledge to be made. This is captured by Newton's famous statement:

> "If I have seen further it is by standing on the shoulders of giants."

79 As detailed in Appendix Two, the industry categories where these benefits were allocated were 17 Monash industries that make up the Metal Product Manufacturing, Machinery & Equipment Manufacturing and the Communication Services sectors. Based on case study analysis of ARC research outcomes, these appear to be the industry areas where the majority of benefits are realised.

80 Reflected for instance in the useful average economic life of a patent being around 10 to 15 years.

An associated argument for the presence of increasing returns to scale in a single, smaller country like Australia is that further building the base of the innovation system would take Australia closer to the technological frontier and hence Australia would be better able to more fully integrate research findings from the rest of the world (whence 98 per cent of new knowledge comes) into Australia's own research efforts. Econometric analysis suggests that countries closer to the technological frontier are better able to benefit from foreign R&D[81]. Increasing ARC funding would therefore lead to a relative increase in the benefits generated from foreign research.

Decreasing Returns

The argument most commonly made for the presence of diminishing returns to scale from basic research is that *in any particular field of research* the easy discoveries have been made and that making further discoveries requires a progressively greater input of research resources to be made.

A related argument for decreasing returns to scale from increasing ARC funding centres on the fact that the ARC currently funds only what it considers to be the best research proposals and that expanding research funding runs the risk of research being supported that is of an inherently lower quality and hence potential impact. Extending funding would therefore imply that the ARC would begin to fund progressively less excellent research and that outcomes would therefore be expected to gradually diminish towards the average for all public sector R&D funding. However, at the moment the success rates in Discovery-Project applications are much lower than the threshold for such diminishing returns to set in. Furthermore, decreasing returns could also be mitigated against if rather than increasing the *number* of grants the average *size* of grants was increased. *Backing Australia's Ability* committed the ARC to increasing both the success rate for Discovery-Project applications and the average grant size.

Constant Returns

There are a number of arguments for constant returns to scale from increasing ARC funding. First, it could be argued that we are currently some distance away from the optimal level of investment in R&D with the implication that potentially excellent research is not being funded currently. An indicator of this is the still relatively low success rate for researchers applying for ARC grants. In this situation increasing ARC funding will continue to support excellent research. Second, the ARC because of its high degree of flexibility in determining the research it is prepared to fund and its focus on breakthrough research is more able than some other elements of the research community to shift away from areas of declining research potential. Thirdly, the emergence of new, high potential fields of research means that the ARC has the opportunity to shift resources to these areas.

In the absence of any conclusive arguments for either increasing or diminishing returns to scale from research funded by the ARC, and given the still relatively low success rates in applications for ARC grants (which says something about the available pool of excellent research proposals), it appears reasonable to assume constant returns to scale are likely to be associated with increasing ARC funding from current levels over the relevant range – ARC funding would need to be increased by very large amounts for the risk of decreasing returns to become significant.

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[81] Griffith, R., Redding, S., Van Reenen, J., (2001)

7.2 Key findings from 'bottom up' scenario

The 'bottom up' scenario attempts to isolate the economic impacts associated with one year of ARC funding, namely 2003, on the economy over the period out to 2018. Time lags associated with the commencement of various benefits flows have been taken into account, and the modelling period ends five years after the final benefits resulting from the ARC funding have commenced.

Table 7.1 sets out the impact of 2003 ARC funding on three key economic variables over the 2003-2018 period.

Table 7.1

IMPACT OF 2003 ARC FUNDING ON AUSTRALIAN MACROECONOMIC VARIABLES

Deviation from forecast with no 2003 ARC, in $m*																
	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18
Real Consumption	-405	-18	4	0	34	36	39	41	78	81	130	137	144	152	159	166
Real Investment	-204	14	15	14	26	25	24	22	35	34	60	56	54	53	51	50
Real GDP	-47	-37	-27	-23	21	26	31	35	82	89	159	173	184	195	205	216

*in 2003 prices

Source: CoPS modelling, see Appendix 2 for details

The modelling of the expected impacts from ARC funding in 2003 alone indicate that real GDP (plus $216 million) and real investment (plus $50 million) in 2018 would be expected to be higher in 2018 than they would have been in the absence of ARC funding in 2003.

Real consumption is perhaps the best measure for overall economic welfare. The impact on real consumption from ARC funding in 2003 is that real consumption (2003 dollars) in 2018 is $166 million higher than it would have been without that funding being made. The Net Present Value (in 2003 terms) of the cumulative impacts on real consumption over the period 2003-2018 is $268 million[82]. While funding the ARC in 2003 was equivalent to an $18 contribution from each person in Australia, the returns generated from the ARC's activities are equivalent to consumption being $14 per capita higher in 2003 than it would have been if this contribution to the ARC had not been made. This return is the net present value of real consumption per capita over the 2003-2018 period above that which would have been enjoyed had the ARC not been funded in 2003 (i.e. the $18 has been recouped and an additional $14 in real consumption generated).

Given that the knowledge and skills generated through 2003 funding will begin reaching the end of their useful life after 2018 and that benefits accruing after 2018 would be heavily discounted in net present value calculations, this represents the bulk of all reliably measurable benefits that will be attributable to the ARC funding made in 2003.

[82] This figure is based on a 5 per cent annual discount rate being applied to impacts in future years

Section Eight

Conclusions

8.1 Key findings

Benefits from ARC research funding are significant and delivered through multiple channels. Key measurable benefit channels identified in this study were:

- benefits from building the basic knowledge stock;
- benefits from generation of commercialisable intellectual property;
- benefits from improving the skills base;
- benefits from improving access to international research; and
- benefits from better informed policy making.

Significant health, environmental, social and cultural benefits may also occur due to ARC funding. However, within the time and data availability constraints of this study it has not been possible for such benefits to be quantified in economic terms.

'Top down' findings

The review of the literature on technological progress and productivity growth suggests that technological change is responsible for around half of multi-factor productivity growth in advanced economies and that R&D, such as that funded through the ARC, is an important contributor to technological progress in Australia. Consideration of both the growth literature and the role of the ARC within the Australian innovation system suggested that a 50 per cent social rate of return represents a reasonable 'ball-park' estimate of the returns from ARC funding in Australia[83] (compared to 25 per cent for all publicly funded R&D in Australia).

It must be stressed though that the results of the 'top down' analysis, because they are based on the average impacts of research funding in a number of developed economies, should be viewed as providing a plausible order of magnitude of the impact of ARC research funding rather than a precise figure based on detailed consideration of the links between ARC funding and associated benefits that have been observed in Australia. The generation of such Australian-specific results requires application of the 'bottom up' analysis that is detailed below.

'Bottom up' findings

Table 8.1 sets out the measured returns from ARC research funding in each of the six key benefit areas.

[83] These findings are within the range (25 to 90 per cent) of the social rate of return to Australia's R&D expenditure estimated by the Industry Commission in its 1995 report, *Research and Development*. It should be noted however that the IC report looked at returns on all R&D, not just publicly funded R&D, and that private R&D is generally found to have a higher social rate of return than public R&D.

Table 8.1

SUMMARY OF BENEFITS FROM ARC FUNDING OF RESEARCH

Category of Benefits	Measured Benefits
Benefits from building the basic knowledge stock	In this area an 10% social rate of return on average from ARC funding (some ARC funding generates higher returns in this channel and other types of funding lower returns) with a ten-year time lag was identified. This is based on the relative success of ARC-funded research finding a route to use and the high pay-offs achieved when this occurs.
Benefits from generation of commercialisable intellectual property	In this area an average 3% social rate of return from ARC funding with a ten year time lag was identified. This estimate is based on observed impacts from commercialisation of ARC-funded research over the past 25 years.
Direct benefits from improving the skills base	In this area an average 12.5% social rate of return from ARC funding with a four-year time lag was identified. This estimate is based on observed output impacts from the skills formation to which the ARC contributes.
Benefits from improved access to international research	In this area an average 7.5% social rate of return from ARC funding with an eight-year time lag was identified. This estimate is based on the level of access to international research funding that the ARC enables Australia to gain and the returns we obtain from this international research.
Benefits from better informed policy making	In this area an average 6% social rate of return from ARC funding with an eight-year time lag was identified. This estimate is based only on the observed impacts associated with microeconomic reform in Australia and the assumption that the ARC contributed only 0.25 per cent to microeconomic reform policy.
Health, environmental and cultural benefits	While the benefits in this area are likely to be significant, it has not been possible within the time constraints of this study to estimate returns in monetary terms.

Based on our conservative 'bottom up' analysis of benefits from ARC research funding, the total social rate of return on ARC investment in Australia is estimated at 39 per cent. However, much of this return accrues with considerable time lags.

These findings provided the basis for subsequent modelling of the expected economic impacts from ARC funding in 2003. The modelling indicated that, due to ARC funding in 2003 alone, real GDP (plus $216 million) and real investment (plus $50 million) would be expected to be higher in 2018 than they would have been in the absence of ARC funding in 2003.

The impact on real consumption, a good proxy for overall economic welfare, from ARC funding in 2003 is that real consumption (2003 dollars) in 2018 is $166 million higher than it would have been without that funding being made. The Net Present Value (in 2003 terms) of the cumulative impacts on real consumption over the period 2003-2018 is $268 million[84].

Given that the knowledge and skills generated through 2003 funding will begin reaching the end of their useful life after 2018, this represents the bulk of all reliably quantifiable benefits that will be attributable to the ARC funding made in 2003.

The level of benefits set out above (based on a total social rate of return of 39 per cent) are lower than those predicated by the theoretical 'top down' approach to measuring benefits from ARC research funding (which suggested a social rate of return for ARC-funded research of over 50 per cent). This is however not a surprising result.

[84] This net present value figure is based on a 5 per cent real annual discount rate being applied to impacts in future years

Unlike the theoretical analysis, our observation-based approach factors in only those benefits that could be reasonably identified and quantified and factors in the time lags associated with these benefit flows. Our 'bottom up' analysis excluded several important potential areas of benefits such as health, environmental and social/cultural benefits. It is also likely, given the richness of the potential menu of benefit channels, that we have not fully identified all the benefits that have accrued in relation to the use and commercialisation of basic knowledge. Due to the partial nature of the measurement of benefits and the fact that throughout this report we have used conservative assumptions in measuring returns on ARC funding, the measured social rate of return should be seen as being as approximating a 'lower bound' estimate of returns.

Another factor impacting on the level of returns projected for ARC funding is that estimates of future benefits are based on past observed rates of return. As is discussed in section 8.2 below, there is reason to believe that returns from ARC funding, particularly in the areas of commercialisation and the use of basic knowledge, may in fact be higher in the future than they have been in the past.

Notwithstanding the conservative nature of our estimates, ARC funding in the year 2003 alone is estimated to produce significant net benefits for the Australian economy over the period to 2018. While funding the ARC in 2003 was equivalent to an $18 contribution from each person in Australia, the returns generated from the ARC's activities are equivalent to consumption being $14 per capita higher in 2003 than it would have been if this contribution to the ARC had not been made. This return is the net present value of real consumption per capita over the 2003-2018 period above that which would have been enjoyed had the ARC not been funded in 2003 (i.e. the $18 has been recouped and an additional $14 in real consumption generated).

Given the significant economic returns on ARC funding in the past and the strong prospects for even higher future returns on ARC funding, the continued activities of the ARC are likely to make a substantial contribution to higher Australia standards of living in the future.

8.2 Looking forward

The key findings from this study indicate that, as a result of continued ARC research funding, the performance of the Australian economy is projected to be significantly stronger by the end of the decade than it would otherwise be.

However, there is reason to believe that the actual contribution of ARC-funded research to the Australian economy in the future may in fact be larger than that derived through the conservative assessment of ARC economic impacts used in this study. This is a consequence of factors both within the modus operandi of the ARC itself and external to the ARC which suggest that the economic impacts from ARC activity may be relatively greater in the future than they have been over the past decade. The three factors we have in mind are:

- improvements in the future positioning of the ARC;
- improvements in a number of complementary elements of the Australian innovation system which influence "routes to use" and "routes to market";
- the likelihood of the emergence of new, breakthrough areas of research which will spur the development of new high-technology industries.

Future ARC positioning

The ARC was created as a separate government agency with a new vision for the way in which research funds, distributed on the basis of competition and research excellence, can serve the national interest by linking cutting edge fundamental research to the national innovation system.

The increased funding for the ARC provided in *Backing Australia's Ability* has enabled the ARC to provide support in ways which are likely to enhance the returns being reaped from ARC-funded research. Notable in this respect are the ability to fund larger projects, fund a higher proportion of excellent research proposals, increase investment in centres of research excellence and increase support for researchers. Given the lead times involved the full benefits from this will be seen only in the future.

The ARC is also committed to the continual review of its own investment practices to ensure that greater returns are achieved for a given investment of financial resources. In regards to improved ARC practices, key changes that may improve outcomes in the future include:

- greater emphasis on improving knowledge flows and facilitating industry/academic interaction – improving prospects for commercialisation of research and skills formation and transfer;
- greater focus on centres of excellence — improving the critical mass of research in key prospective areas and likely generating scale efficiencies within the research sector;
- a greater focus, across a number of grants programs, on identification of possible paths to commercialisation — further improving the prospects for research to be commercialised; and
- a greater emphasis on building international linkages and connecting Australian researchers to global research networks.

Each of these elements could result in an even greater rate of return on ARC funding being achieved in the future than has been the case in the past.

Improvements in the national innovation system

Also significant for the prospective future returns from ARC activities are improvements occurring in other complementary elements of the national innovation system. For a given investment in ARC-funded research the returns achieved are heavily dependent on a number of complementary factors or conditions in the research receptors that are outside the control of the ARC. Three important elements of the innovation system whose performance complements ARC-funded research are considered in turn.

As noted by the Productivity Commission (1995), an important economic role of basic research is to raise the return on more applied R&D. Over the period from 1985 to 1996 business R&D increased by rates in excess of those shown in many other OECD countries. Following a period in which business R&D growth stopped, in the last year for which statistics are available there was a solid lift in business R&D. If this growth can be continued the potential for ARC-funded research to raise the return on business R&D should be correspondingly increased. The government has in place a range of instruments designed to increase business R&D which, taken together with the competitive imperative for many industries to innovate, should see business R&D increasing in the future. Whether the increase will be adequate to Australia's future needs is a question beyond the scope of this study.

Not only are the level of business R&D and the number and quality of scientists, engineers and technologists employed by industry important complements to ARC-funded research, but also the degree of linkage between publicly funded research and business researchers. The ARC's Linkage grants are directly focussed on improving performance in this area. The Government's Cooperative Research Centres program is the biggest scheme explicitly targeted on building such linkages. Other schemes also have this objective as one of their elements. It is reasonable to expect that public-private linkages are likely to grow in the future.

Turning to the prospects for commercialising the results of knowledge generated by ARC-funded research, an important consideration will be the availability of business incubation services, pre-seed capital and venture capital. The Commonwealth and State Governments have put in place a number of programs aimed at improving business incubation services — a notable one has been the Building on IT Strengths incubator funding program. *Backing Australia's Ability* provided over $70 million for a pre-seed capital fund. More recently actions have been taken through the taxation provisions to attract venture capital investments to Australia. Taken together, these actions should have improved the prospects for the successful commercialisation of public sector R&D.

Also influencing the potential for commercialising ARC-funded research is greater focus on ensuring that publicly funded research institutions have appropriate intellectual property management practices in place — the ARC itself has supported the development of best practice guidelines for management of IP. This is important as, unless there is clarity of IP ownership and clear pathways via which institutional knowledge can be accessed, prospects for successful conversion of IP into new products and processes are severely curtailed.

An independent working group supported by the Prime Minister's Science, Engineering and Innovation Council secretariat has noted that commercialisation of public sector research is on the rise in Australia. However, the working group believes there may currently be many missed opportunities that could deliver economic returns. Highlighting the scale of potential benefits that improved commercialisation performance could bring, the working group proposed:

> "If we can grow 200 – 250 more Australian research-based companies like five of those shown in this report over the next five years, the prize would be around $20 billion added to our annual export earnings."

PMSEIC, (2001), *Commercialisation of Public Sector Research*, Paper for seventh meeting, 28 June 2001

Future research fields

The third factor which will exert an important impact on the returns that are likely to be generated on research funded by the ARC is the emergence of prospective new areas of research. In recent years we have seen major new areas of research and knowledge creation develop with large implications for the economy and society as a whole. Some of the most far-reaching have been:

- information and communications technology;
- biotechnology;
- materials technology; and
- nanotechnology

These areas will undoubtedly continue to offer fruitful fields for further development for the foreseeable future. Important applications in biomedical and pharmaceutical, human and animal health, environmental monitoring, mining, manufacturing and telecommunications will continue to emerge.

Over and above these areas of research, with the increasing proportion of resources being devoted to research in the advanced industrialised countries it is highly likely that new, highly prospective technologies will emerge. The chances of the discovery of new technologies slowing down significantly and diminishing returns to research setting in are not very high.

Conclusion

The ARC occupies an important place in the funding of research in Australia. It is the body with primary responsibility for funding excellent research in the Universities in fields other than clinical medicine and clinical dentistry, which are the responsibility of the NHMRC.

The ARC's importance to Australia's scientific capability was recognized in the Chief Scientist's report *The Chance to Change* (2000) and the subsequent innovation statement by the Commonwealth Government *Backing Australia's Ability* (2001) which announced that ARC funding would be doubled over a five-year period. The funding for the NHMRC had been doubled a year or so earlier following the Commonwealth Government's consideration of the *Wills Report* (1998). Both the Chief Scientist and Peter Wills in their reports made the important point that support for research represented an investment and that a consequence of this is that the community should expect to gain a return upon the investment made.

While it has been presumed that the returns on ARC-funded research are high, both in economic and non-economic terms, this report represents the first systematic attempt that has been made to calculate a well based estimate of the rate of return being achieved in practice.

The rate of return we have estimated, despite being deliberately based upon conservative foundations, is impressive. This is particularly so when account is also taken of the important channels of benefit for which we have not been able to provide quantitative estimates of returns. The Australian community is getting a strong rate of return from ARC-funded research. Looking ahead, the new ways in which the ARC manages its portfolio of investments, the strengthening of the national innovation system (the process of going from minds to markets) and the prospective waves of technological change in the future all suggest that the rate of return on ARC-funded research is if anything likely to increase.

Appendix One

Case studies of ARC-funded research projects

Cochlear Limited

With support from both the University of Melbourne and a number of Commonwealth research grants, during the late 1970s Professor Clark at the University of Melbourne developed the prototype for the Cochlear implant. Professor Clark began research into the feasibility of cochlear implants in 1967, and trialled the implant in 1978. Cochlear Limited was formed in the early 1980s to commercialise this technology. The company is now the world leader in hearing implant products, providing cochlear implants for children who are deaf and adults who have become deaf. Today, Cochlear Limited on of Australia's top 50 companies with a market capitalisation of over $1.9 billion.[85]

Cochlear employs over 700 people, 400 of them in Australia, with head office, manufacturing, and the majority of R&D remaining in Australia. It has regional offices in the USA, the UK, Belgium, Switzerland, Germany, Japan and Hong Kong.[86]

Cochlear's nuclear product range is available in more than 70 countries, with over 95 per cent of sales generated outside Australia. Since the first commercial implant 20 years ago, Cochlear's award-winning nuclear range has been implanted in nearly 40,000 people worldwide. Cochlear is the only publicly listed company in this industry and seeks to achieve strong ongoing growth of at least 20 per cent.[87]

Cochlear was formerly a business segment of Nucleus Limited, with Nucleus Limited itself being a wholly-owned subsidiary of Pacific Dunlop Limited. It was decided by Pacific Dunlop Limited in 1995 to establish the hearing implant division as a separate listed company in order to facilitate the future growth and expansion of the company's activities and markets. This was achieved through a public float of the 50 million ordinary shares of Cochlear Limited on the Australian Stock Exchange at $2.50 per share. Priority access to the shares in Cochlear was given, under the public issue, to Pacific Dunlop shareholders, various research centres and technological institutes involved in hearing-impairment and implant research.[88]

Cochlear has been one of the major success stories on the Australian sharemarket over the last five years, experiencing enormous growth in revenue and operating profits and providing substantial share returns for investors over this period. The company's share price has increased from an initial issue price of $2.50 in December 1995 to a price of $33.30 in August 2003 (with a peak of $48 in December 2001).

85 http://www.asx.com.au
86 Cochlear Annual Report 2002, accessed from http://www.cochlear.com.au
87 Cochlear Annual Report 2002, accessed from http://www.cochlear.com.au
88 Online case studies, accessed from http://www.mcgraw-hill.com.au/mhhe/fin/peirson8e/stu/casestudy04.doc

Sales revenue for the year ending June 2002 for the company was A$255 million, an increase of 16 per cent over the previous year, and an increase of 56 per cent since 2000. This result was driven by strong system sales, which grew by 21 per cent in 2002. Cochlear is a significant investor in R&D, with $37.7 million spent on R&D in 2002. R&D expenditure has increased significantly over recent years, increasing by 30 per cent between 1998 and 2002.[89] Profit after income tax in 2002 was $40.1 million, an increase of 29 per cent from 2001. The first half of 2002-03 has provided record half year profits, with system sales 22 per cent higher in December 2002 from December 2001. This resulted in $27 million profit after tax, an increase of 57 per cent from the previous year. Cochlear now hold global market share of 65-70 per cent.[90]

ResMed

Dr Peter Farrell formed the ResMed group of companies to commercialise technology developed by Dr Sullivan at the University of Sydney in the 1980s. This research was supported by both the University and through Commonwealth research grants. Dr Sullivan and his colleagues invented a method of treatment of one a major forms of sleep disorder, Obstructive Sleep Apnoea (OSA). Left untreated, OSA can severely affect quality of life, health and mortality, and is strongly associated with hypertension, heart disease and stroke. The disease affects approximately 10 per cent of adult males in Australia.[91] Based on technology developed by Dr Sullivan, ResMed developed a range of masks that provide continuous positive airway pressure, thus treating the main cause of OSA.

ResMed has grown into an international success story, after starting in 1989 as ResCare Ltd, a company formed by Dr Farrell. ResCare raised $1.2 million from staff and private investors to begin production of devices for the treatment of OSA. Sales began in Australia in 1989, the USA later that same year and in Europe in 1990. Research and development undertaken by ResCare was supported by an IR&D Board grant of $150,000 in 1989 and an Austrade International Business Development Grant of $110,000 in 1990.[92] During these early years the company faced difficulties with attracting interest from potential financiers, primarily due to perceptions about its one product focus and a lack of understanding about OSA.

In June 1995 the company registered on the Nasdaq exchange as ResMed Inc, raising US$24 million.[93] In late 1999 the company transferred to the New York Stock Exchange and later co-listed on the Australian Stock Exchange. Subsequently, wholly owned subsidiaries have been formed (such as in the UK) or successful distributors have been acquired.

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89 Cochlear Limited, *Annual Report 2002*, accessed from http://www.cochlear.com.au

90 ASX Announcement/Media Release, accessed from http://www.asx.com.au

91 ResMed Corporate Fact Sheet, accessed from http://www.resmed.com.au

92 http://www.atse.org.au/publications/focus/focus-barnes.htm.

93 http://www.atse.org.au/publications/focus/focus-barnes.htm.

ResMed currently employs approximately 1,300 staff (over 400 of which are located in Australia). ResMed revenues exceeded $400 million in 2002-03. It has a current market capitalisation of A$1.9 billion on the Australian Stock Exchange and US$1.3 billion on the New York Stock Exchange.[94] As of June 2002, the company's compound annual growth rate was 36 per cent for revenue and 44 per cent for net income (using 1995 as a base).[95] The total size of the 'sleep industry', of which ResMed is the market leader, was valued at $1 billion in 2001 worldwide, and growing at 20 per cent per year. ResMed operates through direct offices in the United States, Australia, Germany, France, Sweden, the United Kingdom, New Zealand, Singapore, Malaysia, Japan, and through a network of distributors in more than 60 other countries. More than 95 per cent of ResMed products are exported.

Critical factors which influenced the success of ResMed include:

- *the research base* — Professor Sullivan's group has always led this field of research;
- *attracting the best overseas researchers through strong research credentials* — which enabled ResMed to access international markets;
- *establishing intellectual property* — the original patents enabled ResMed to keep potential competitors out of Australia for approximately five years. This was enough time to enable ResMed to start selling and establish an important base in the US.[96]

VentrAssist™

The VentrAssist™, currently being developed by publicly listed company Ventracor, is a rotary blood pump designed to take over the pumping function of the heart's left ventricle. This new technology provides a much longer period of pumping support than current blood pumps. It does not require the removal of the heart itself, but rather assists the blood pumping function of a failing heart, providing a long term alternative to transplantation.

The VentrAssist™ was initially developed by a group of researchers at the University of Technology in Sydney (UTS) and the University of New South Wales. In 1995, Dr John Wood approached Professor Vic Ramsden to develop a prototype rotary blood pump. They established the company Micrometrical Industries, which, in conjunction with UTS, later applied for and received an ARC Collaborative Grant of $80,000 per annum for 3 years, commencing in 1997, to get the research going. Micrometrical Industries provided matching funds. In 1999 the team received further ARC support through a $150,000 SPIRT grant.

The rotary blood pump is one of several styles of blood pumps being developed and researched around the world in an international effort to develop the world's first implantable blood pump. At present, congestive heart failure can be cured only by organ transplantation.

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[94] http://www.nyse.com/cgi-bin/ny_quote?sym=RMD.

[95] ResMed Corporate Fact Sheet, accessed from http://www.resmed.com

[96] Australian Academy of Technological Sciences and Engineering (NSW Division), *Commercialising Innovation "The Second Step"* Workshop Proceedings Sydney – 10 May 2001, p. 26.

Blood pumps currently used are pulsatile pumps. They are implanted as a temporary ‘bridging’ measure to keep a patient alive long enough to receive a heart transplant. Unfortunately traditional blood pumps have an effective lifespan of two years only and there are problems with infection, blood damage, blood clotting and maintenance of the equipment. The surgery itself is high-risk: one in seven patients does not survive the surgery. Patients also need to recharge the battery for the device every few hours.

The VentrAssist™ rotary blood pump is a significant departure from current artificial heart technology because it has removed the seals, shafts and bearings which have caused serious side effects for patients in the past, including blood damage and blood clotting. The rotary pump is operated by a small and efficient motor drive and is designed to support the work of the human left ventricle for five years or longer.

The market for this product is estimated to be between US$7.5 billion and US$12 billion annually. It is estimated that, in the United States alone, there are 81 million people suffering from various forms of cardiac disease. This number is growing by 6.8 million per year. There are obvious public health benefits from development of this new product. Around 44 per cent of all deaths in Australia are directly related to heart disease and about 750 Australians die from congestive heart failure every year. Many of these patients die while they are awaiting transplantation of a scarce donor heart. A major advantage of the new technology is that it can be produced at a lower cost than other pumps on the market.

Ventracor is currently has a market capitalisation of $200 million. A pilot trial of the VentrAssist™ is currently being undertaken at the Alfred Hospital in Melbourne, consisting of about 10 patients. A global trial is timed to begin in the second half of 2003.

BioSignal Pty Ltd

BioSignal Pty Ltd is the privately owned company established to develop and commercialise technology developed at the University of New South Wales’ Centre for Marine Biofouling and Bioinnovation (CMBB). Through research funded by the ARC, Dr Peter Steinberg and Professor Staffan Kjellberg from the Centre discovered a naturally occurring compound on seaweed that is resistant to ‘biofouling’. Biofouling is the layer of slime that builds up on many surfaces. The furanone compound resists biofouling by emitting chemical signals.

The practical applications of these compounds are considerable. The growth of marine organisms, such as barnacles, on the hulls of ships is a major problem. It costs shipping and other marine industries over $6.5 billion per year globally to control this problem with paints which are highly toxic to the marine environment. The team from CMBB is investigating methods for treating surfaces, such as ship hulls, with furanone compounds by incorporating the compounds into paints and polymers. There are considerable environmental benefits of this treatment, as furanone compounds are biodegradable and likely to have low-level toxicity to humans.

There are also many potential health benefits from application of this technology to the medical and pharmaceutical industries, particularly with respect to combating bacterial infection. Instead of killing bacteria, as do antibiotics, furanone compounds could resist bacteria and persuade them to settle elsewhere. Other applications include more effective deodorants and domestic cleaning products, toothpaste that keeps plaque away and contact lenses that do not cloud over.

The ARC has provided $1.1 million funding over nine years for the development of this technology. Biosignal Pty Ltd is currently in collaboration with a number of international companies developing numerous applications of this technology. These products are in the development phase, with product-related revenues anticipated by 2005. The projected revenue from commercialisation in 2005 is $2.5 million, rising to $63.8 million by 2008.

Radiata

Radiata Communications developed groundbreaking chip technology for enabling very high-speed communications over wireless local area computer networks, or LANs. Radiata built a 'wireless engine' capable of sending data through the air at 54 megabits per second, during a time when the industry was just getting used to wireless networks that could carry bits and bytes at 11 megabits per second (almost 200 times faster than a standard 56K modem).

This new technology would make it possible to run multiple channels of full motion video and other multimedia items between PCs and other electronic devices such as phones and television sets. The business market alone for this technology is estimated to reach $US1 billion by 2005.

Radiata was founded in 1997 by Dr David Skellern and Dr Neil Weste to commercialise development work (funded in part by the ARC) by Skellern and Weste in conjunction with the CSIRO. Dr Skellern had spent most of his career as an academic at Macquarie University where he founded the institution's new microelectronics department. Both Skellern and Weste had experience working in the US for technology companies, including Hewlett-Packard, Bell and Phillips. The network of engineering and commercial companies that the pair developed during their time in the US served them well when it came to pitching Radiata's technology.

Cisco Systems purchased Radiata Communications in November 2000 for $US295 million. Cisco already owned an 11 per cent stake in the company after providing early stage funding in 1999.

Quantitative Phase Technology

Quantitative Phase Microscopy (QPm) technology was developed by University of Melbourne physicist and ARC Federation Fellow, Professor Keith Nugent and his team. The technology enables a standard optical microscope to perform like a specialised phase microscope. It also, when used in conjunction with its accompanying software, allows, for the first time, quantitative measurements with a standard microscope. For example, a researcher studying cells in the normal, two-dimensional view can now measure the volume of cells, by gaining access to three-dimensional information.[97]

[97] National Survey of Commercialisation 2000.

Conventional phase microscopy was developed in the late 1940s and allows the viewing of unstained specimens by using the light phase amplitude differences within microscopic objects. When an unstained biological specimen is observed in a normal microscope, it is often difficult to see because most biological material is uncoloured and transparent. A phase microscope picks up the differences in refractive index between the object and the background; created when light passing through an object is deviated. QPm was developed by Professor Nugent, with ARC funding of approximately $765,000. The technology adds a new dimension to scientific research by allowing users to make quantitative measurements. QPm has given researchers a new tool, providing increased capacity for new scientific discovery.

In 2000, a new company, IATIA, was floated to commercialise QPm technology. Using an ARC linkage grant, researchers are now studying new ways in which the QPm can be applied. Since publicly listing, IATIA has launched two new products, QPe and QPt. In 2002 the company had a market capitalisation of $30 million and 30 employees.

Securities Industry Research Centre of Asia-Pacific (SIRCA)

By pooling several ARC grants in 1992, University of Sydney Professors Michael Aitken and Peter Swan created the Securities Industry Research Centre of the Asia Pacific (SIRCA) as their own research centre.

SIRCA was established as a joint venture between four universities. The purpose of the centre was to work with industry to undertake research into Australia's capital markets, with the aim of improving market efficiency. SIRCA now has 25 member universities across Australia and New Zealand.

SIRCA is a not-for-profit company limited by guarantee and governed by a board comprising senior representatives from member universities, commercial organisations, government representatives and industry associations. Aided by almost $5 million of ARC funding since 1994, the centre's research has involved every sector of the Australian Securities Market, leading to various technological innovations, and has directly improved Australia's market efficiency.

The work undertaken at the centre has led to considerable benefits to the efficiency of Australia's Securities Industry. The direct impact of the research on market efficiency is best illustrated by the work of Professors Aitken and Swan on transaction taxes. Their modelling of the relationship between trading activity and transaction costs on behalf of the ASX helped convince State Governments in Australia to halve stamp duty. The net effect was a $4 billion increase in the value of securities and a 20 per cent reduction in the costs of trading — potentially millions of dollars.

Another major innovation arising from the research program has been the creation of an independent company, Asia-Pacific Capital Market Limited (ACM). The central purpose of the ACM is to co-ordinate resources of universities, industry and governments to enhance the international competitiveness of regional capital markets. ACM builds, maintains and shares research infrastructure resources to support research into the financial services industry. These resources include super-computing power (MEMlab), software, data and programming services. MEMLab was funded by a $700,000 ARC Research Infrastructure Equipment and Facilities Grant and a subsequent $1.2 million contribution by the Australian Stock Exchange.

The development of expertise in research infrastructure resources has lead to the creation of leading-edge software which to date has been sold to a number of international clients, including the Russian Central Bank, the Moscow Inter-bank Currency Exchange, the Jakarta Stock Exchange, the Hong Kong Stock Exchange, the Oslo Stock Exchange and the Hong Kong Securities and Futures Commission. The sale of software attracts some $3 million to $5 million in export income per annum. The software, known as SMARTS (Securities Markets Automated Research, Training and Surveillance), was designed by Professor Aitken and funded by Computershare Limited, an Australian public company.

The software is the first off-the-shelf product of its kind in the world. An educational version of the software, UNI-SMART has also been developed and distributed to a number of universities around the Asia-Pacific region for students to recreate the trading floor of the stock exchange.

In summary, the outcomes of the research have been:

- the design of world-class software (SMARTS) now being used commercially by regulators and exchanges around the world for market surveillance/integrity;
- the creation of research commitments from the industry partners, amounting to at least $1 million per annum to 2004;
- significant research collaboration between six major universities;
- international collaboration with researchers from NZ, US, Hong Kong and many others; and
- the design of unique research-based training materials currently being used in post-graduate and under-graduate teaching programs.

Boger Fluids – Viscoelastic Fluid Mechanics

Boger fluids derive their name from the discoverer, Professor David Boger. Professor Bogor is an internationally renowned rheologist – someone who studies the flow and deformation of materials. Professor Boger and his colleagues discovered a new class of material behaviour and developed revolutionary experimental techniques over the last 25 years, with the ARC providing funding of $1.4 million between 1979 and 2000. Professor Boger's research has led to collaboration with research groups in Australia, Europe, Canada, Japan and the USA.

Boger fluids are viscoelastic fluids. Understanding the mechanics of viscoelastic fluids allows various industries to make products like ink, paint, tomato sauce, toothpaste and ointments that flow perform in a predictable way.

The extent of Professor's Boger work in viscoelastic fluids over the last 25 years is considerable. The best-known application of Professor Boger's research has been to the problem of toxic 'red mud' residues during the processing of alumina. The implication of this technology for Australia, as the world's largest producer of alumina, are significant. Alumina production generates vast quantities of potentially hazardous waste. The standard disposal practice of pumping the highly caustic red mud into settling pools created considerable environmental risks such as groundwater contamination. In the early 1980s, Prof Boger, jointly funded by the ARC's predecessor organisation and Alcoa Australia, developed a more effective red mud waste disposal system. The research yielded a revolutionary 'dry disposal' scheme. By identifying the properties of the red mud, Prof Boger made the sticky residue into a fluid by draining and stirring the residue until it became liquid enough to be pumped down a pipe to a disposal area where it would dry and resolidify. Much of the caustic waste was recovered, the dry solid stacked until it formed a stable surface, overlaid with soil and planted with grass and trees.

The major benefits of this new technology were decreased land use and much reduced long-term environmental liabilities for the industry, as well as significantly reduced environmental costs to the community. For the aluminium industry, the cost savings over old techniques are estimated to be over $10 million per year, and will continue for the next century, given current resources. The technology has also been adopted in the nickel and gold sectors.

Prof Boger also applied the technology developed for the aluminium industry to waxy crude oil transportation. Prof Boger and his laboratory worked with Delhi Petroleum in Queensland to convert a specific form of crude oil from a solid to a liquid (at room temperature) so that the $180 million Jackson-to-Moonie pipeline could operate efficiently. The pipeline was constructed to transport crude oil from Jackson in the southwest corner of Queensland to Brisbane. The particular crude oil is high in wax content and behaves like a solid at room temperature. Boger's laboratory at the University of Melbourne tested the flow properties of crude oil and modified these properties, creating a liquid that could flow at room temperature. This technology was been used to examine similar problems for BHP and Petrocorp. Orica has provided funding to further develop the work.

Proteome Systems Limited

Proteome Systems Limited (PSL) is the privately owned company founded in 1999 to commercialise technology developed with the support of ARC funding by Professor Keith Williams and his team at Macquarie University.

PSL is recognised as a world innovator in the development of proteomic technologies. In just three years of existence PSL has established itself as a player in the emerging 'post-genomic' phase of biotechnology, where companies are moving beyond genetic manipulation to engage directly with the core building blocks of life: proteins and their biochemical linkages. PSL's four main areas of activity are drug discovery for human disease, agricultural biotechnology, scientific instruments and consumables for proteomics technology, and protein databases and tools.

Proteomics, the science of proteins, is the global study of the interaction and modification of proteins in the body. This study promises to be the pathway to a detailed understanding of health and disease in humans, and an extension of understanding in animal husbandry and agriculture. Proteomics offers medical research groups and drug companies the possibility of faster, safer and more effective drug design and a better way to diagnose disease.

Dr Williams began working in the field of protein analysis in 1984, as the chair of biological sciences at Macquarie University. Williams established the Macquarie University Centre for Analytical Biochemistry in 1992, and began working with corporations in Australia and overseas on scientific instrumentation. In 1995 Williams founded the Australian Protein Analysis Facility, the first major national facility for the analysis and characterisation of proteins. The facility developed instruments for protein sequencing, including automation.

PSL was founded by six academics, led by Dr Williams, all former Macquarie University research scientists. Since is inception PSL has built powerful partnerships with several overseas companies, including:

- Dow Agrosciences (USA), leading to research into plant proteins;
- Shimadzu Corporation, a manufacturer of scientific instruments, which has led to the development of a patented product for protein identification;
- Sigma-Aldrich, a life science and high-technology company, which recently released, in conjunction with PSL, a line of preparation kits for use in scientific and genomic research.

A large number of computer-driven tools have also been developed at PSL that facilitate the identification of proteins from gene sequences.

PSL employs 100 staff in Sydney and Boston. Turnover in the 2002-03 financial year is forecast to reach $15 million, up from $7.7 million in 2001-02, with the unlisted company valued at $400 million. The global market for the proteomics sector in 2000 was estimated at $US1 billion, growing to nearly US$6 billion in 2005.

Australasian Legal Information Institute (AustLII)

AustLII, the Australasian Legal Information Institute, provides free on-line access to Australian and international legal material—in effect, a public law library on the Internet. AustLII publishes public legal information—that is, primary legal materials (legislation, treaties and decisions of courts and tribunals) and secondary legal materials created by public bodies for purposes of public access (law reform and royal commission reports for example).

The scale and impact of AustLII is impressive. AustLII covers over 100 Australian and international jurisdictions and holds over 80 full-text databases of Australian primary legal materials including legislation of all 9 Australian jurisdictions, decisions of the States' Supreme Courts, the Federal Courts and the High Court, and special collections (the Australian Treaties Library, Industrial Law Project, Reconciliation and Social Justice Library and the reports of the Australian Law Reform Commission). International databases include laws from South Pacific nations and the British and Irish Legal Information Institute. In partnership with the Asian Development Bank, AustLII is providing training in Internet legal research to government lawyers and law reform personnel in 7 Asian nations (China, Mongolia, Pakistan, India, Indonesia the Philippines and Vietnam).

AustLII receives up to 620,000 'hits' per week day from over 30,000 'sessions'. Users include law professionals, researchers and general public. AustLII users include educational institutions (30%), the legal profession & business (25%) community organisations (15%), government (10%), and overseas users (20%). It provides a major database for research in Law and Justice Studies. With over 1.5 million searchable documents, AustLII is one of the largest sources of legal materials on the net.

The argument for free access to AustLII runs parallel to the arguments for publicly funded research. For AustLII, 'maximising access to the law supports the rule of law and a transparent legal system enhances the nation's economic and global competitiveness'. It is, partly, because AustLII gives free access that the databases have been made available for on-line access.

AustLII is built on partnerships. ARC funding is supplemented by funding from the Asian Development Bank, Australian Business Ltd., DFAT and IP Australia. It represents a major investment, totalling $820,000, from the ARC since 1994 and the ARC is the major funding source.

ARC funding for AustLII is cross-disciplinary and cross-programme. In addition to the infrastructure grants, the ARC has supported both the computing development and the databases, including:

- 1997-9 $170,000 ARC Large Research Grant – research on new methods of delivering legal services on the internet through inferencing technologies (on AustLII)
- 1997-9 $200,000 ARC SPIRT Grant for research on new methods of integrating primary and secondary legal materials on the internet, and presenting them to diverse audiences, as part of using the internet to further the process of reconciliation (on AustLII)
- 1996-8 $180,000 ARC Major Grant for research on new methods of legal text retrieval
- 1994 $160,000 ARC funding for the establishment of the Australian Legal Information Institute (includes $50,000 UTS/UNSW contributions).

The research team that developed AustLII is now leading the development of WorldLII, an unparalleled online global legal research facility. AustLII software, infrastructure, expertise and development support have supported the development of other 'LIIs' - British and Irish, Canadian, Pacific Islands and Hong Kong Legal Information Institutes. Launched in 2002, WorldLII already provides access to 300 databases from 51 jurisdictions in 26 countries and acts as an incubator for new national and regional LIIs.

By maximising access to the law, Australasian Legal Information Institute (AustLII) and World Legal Information Institute (WorldLII) support the rule of law and transparent legal systems that enhances Australia's economic and global competitiveness.

The Centre for Cultural Material Conservation

The University of Melbourne Conservation Service commenced operation at the Ian Potter Art Conservation Centre in 1989. The Service was established in recognition of the University's need to provide for the preservation and conservation of its extensive and significant collections of cultural material. The University of Melbourne Conservation Service through the School of Fine Arts, Classical Studies and Archaeology, and the School of Physics, Earth Sciences and Chemistry has received fourteen grants from the Australian Research Council (ARC) since 1990. Central to these studies has been the investigation of artists' materials and techniques and the strengthening of art historical, cultural and scientific knowledge. This information and data are key to improved conservation practice.

With ARC funding, the Service concentrates on three key research areas:

- The investigation of scientific instrumentation, and scientific methods, for the purposes of art materials analysis
- The investigation of the materials and techniques of Australian artists and associated issues such as art fraud and authentication
- The development of collaborative programs in materials conservation including the provision of scientific instrumentation and associated enhanced research capacity across institutions.

Two areas of current research interest include issues relating to analysis for attribution and dating of artworks, and the use and behaviour of artists' materials in the tropical environments.

Analysis of artists' materials and their methods as well as scientific identification of known materials is key to establishing the provenance of an artwork, by investigating attribution and dating. Funding received for the project *Distributed National Network for the Scientific Analysis of Artworks* (1999) enabled infrastructure to be set up at seven key universities, galleries and conservation laboratories. The project uses advanced imaging techniques and equipment funded by the Australian Research Council to examine artists' preliminary work below the finished paint layer, and provides information on the construction of significant paintings. Members of the network are conservators and curators from the National Gallery of Victoria, the National Gallery of Australia, the Art Gallery of New South Wales, Queensland Art Gallery, Artlab Australia, the University of Melbourne and the University of Canberra. This project has supported the development of databases of underdrawing in Australian art, and the forthcoming volume of *Melbourne Journal of Technical Studies in Art* will showcase some of this work.

The other area of research interest, the use and behaviour of artists' materials in tropical environments, results from the Conservation Centre's engagement with Asia since 1996. Previous work with partner organizations in the region highlighted the limited body of research relating to materials analysis and the behaviour of materials in tropical environments.

In 1990 the research programs of the Service were supported by an ARC Special Initiatives Grant for the University Conservator, Robyn Sloggett, to explore research areas that would link the scientific expertise on campus with the research potential of the collections. This initial program examined scientific procedures for the investigation of materials and techniques of Australian artists represented in the University's Art Collection. In 1991-3 Robyn Sloggett, Prof. Tony Klein and Prof. Tom O'Donnell (Heads of Physics and Inorganic Chemistry respectively) were successful in obtaining one Large ARC and Small ARC grants to continue this work. One aspect of this work, the investigation of frames on Australian works, formed the basis for the first volume of the refereed Melbourne Technical Studies in Art. The infra-red work from the 1999 RIEF Grant will provide the material for the second volume to be published shortly.

Leveraging off Small ARC grant funds has been critical to the Service's later success in achieving two RIEF Grants and two Linkage Grants. In addition the expertise in materials analysis resulting from this support has contributed to the development of a substantial commercial operation (with an annual turnover of around $750,000 from fee-for-service and contract work). From its beginnings in 1989 with one conservator the Service now has a staff of twenty working on a mix of University, commercial and research programs.

Recently the Council of the University of Melbourne has approved the establishment of the Centre for Cultural Materials Conservation. An aim of the Centre is to develop post-graduate research opportunities relating to the broader issues of cultural preservation, particularly as these relate to communities and cultures within the Asian-Pacific region.

The establishment of the Centre is a direct result of support from the ARC for conservation research programs at the University of Melbourne. The increasing strength of the research programs in this very important area of cultural conservation and preservation attest to the value of this support.

Jameson Cell

The Jameson Cell is the invention of Professor Graeme Jameson from the University of Newcastle. Professor Jameson began research in 1965 into multi-phase processes. In 1986, after 21 years of research, this work resulted in the invention of a radical new device for the separation of minerals known as the Jameson Cell, which is making a major impact on the Australian mining industry.

The Jameson Cell induced air flotation (IAF) device was invented for the recovery of valuable minerals in mineral processing plants. The Jameson Cell has all the advantages of previous processes used, and not only occupies far less space but is a distinct leap in technology with substantial improvements over existing methods. Costs can usually be recovered in a very short time and the grade of product emanating from the ore concentrators has been improved substantially.

The licensing rights for the Cell were acquired by MIM Holdings Limited, Brisbane. Since that time the Jameson Cell has been installed in numerous major minerals and coal projects on the worldwide market. It is estimated that the commercial value of this technology is in excess of $500 million in export coal each year.

While MIM enjoyed significant success in the mineral industry, Professor Jameson and colleagues pursued alternative applications for the technology. Initially, such applications were in the area of industrial effluent treatment, particularly for dairy and industrial manufacturing applications. It was soon apparent that the Jameson Cell IAF process was excellent for the removal of suspended solids, oil and grease from effluent streams. A couple of demonstration sites were installed during 1993-4 and, following their success, Jetflote was granted the licence for the Jameson Cell for non-metallurgical applications and commenced trading in July 1994.

Environmental Group Limited (EGL) acquired the business of Jetflote Pty Ltd in September 1999, including the exclusive worldwide licence of the Jameson Cell technology for water applications. EGL is an Australian-owned public environmental technology company listed on the Australian Stock Exchange.

The Jameson Cell IAF technology provides a cost-effective alternative to upgrading inland wastewater treatment works since it addresses the problem of algae growth in ponds, thereby allowing water authorities and councils to continue to utilise the benefits of wastewater pond systems. The aim of providing an effective means of simultaneous phosphorus removal is also addressed. The first municipal unit to remove algae and phosphorus from treated sewage (maturation pond) effluent was installed for Wagga Wagga City Council at its Narrung Street Sewage Treatment Plant. The plant, was commissioned in June 1999, and has met or exceeded all performance expectations, producing water suitable for discharge to sensitive receiving waters. Process plants have since been installed for Wagga Wagga City Council and the North East Region Water Authority.

Jameson Cells are installed in Korea and Malaysia for effluent treatment from compressed timber products manufacture and terminal tank washing facilities. In UK the technology is represented by Brightwater Engineering.

There remain numerous application areas for which the Jameson Cell is likely to be a leading-edge technology solution. The process is very compact and cost-efficient compared to traditional technologies. The process is well suited to stormwater and combined sewer overflow (CSO) treatment due to the features of low start-up time, high process rate, and ease of augmentation to an existing site.

Professor Jameson has received a total of $2.1 million in ARC funding from 1979 to 1998. He currently receives ARC funding through the Special Research Centre for Multiphase Processes.

Appendix Two

Modelling report

'Bottom Up' Modelling Scenario: Economic Impact Of Continued ARC Research Funding

Report from the Centre of Policy Studies, Monash University
Prof Peter Dixon, A/Prof John Madden

1. Introduction

The Centre of Policy Studies (CoPS) at Monash University was commissioned by the Allen Consulting Group to examine the effects on the Australian economy of the operations of the Australian Research Council (ARC).

In this paper we report on the impacts of ARC funding of a single year (2003) of research. These effects were estimated via simulations with the MONASH model for the period 2003 to 2018. The model is briefly described in the next section, while the nature of the simulation of ARC operations is outlined in Section 3. In Section 4 we provide the macroeconomic results of the simulations and describe the major economic mechanisms underlying those results.

2. Economic model

MONASH is a dynamic computable general equilibrium model of the Australian economy developed by CoPS for forecasting and for policy analysis. Its antecedent was the comparative-static ORANI model. For a full description of the MONASH model, see Dixon and Rimmer (2002).

In the present study we first conducted MONASH simulations to produce a baseline forecast for the Australian economy for the period 2003 to 2018. These MONASH forecasts incorporated a wide variety of information including: macroeconomic forecasts from the Commonwealth Treasury and other analysts; export volume and price forecasts from the Australian Bureau of Agricultural and Resource Economics; forecasts of tourist numbers from the Bureau of Tourism Research; forecasts of tariff rates from the Productivity Commission; and forecasts of changes in technology and consumer tastes derived from trends calculated at CoPS. Using this information the model generated forecasts for a wide range of variables.

We then repeated our forecasts under the assumption that the ARC had not funded any research during the calendar year 2003. The new forecasts were then compared with the baseline forecasts. Results are reported as deviations (in percentage change terms) of the baseline forecasts for 2003 to 2018 from the hypothetical no-ARC-in-2003 scenario. Thus the results show the effects on the economy over a fifteen-year period following 2003 of actually having undertaken ARC operations in 2003.

3. Modelling Assumptions

The ARC awards grants on a competitive basis for the undertaking of research. It is intended that such research increases knowledge and that one of the benefits of this is to increase the productivity of the nation. In this paper increased productivity in terms of an increase in measured GDP per input is the only benefit from ARC-funded research that we were asked to consider. Thus we leave aside any benefits in terms of consumption of culture, an improved society and the like.

The cost of generating the benefits of the new research is taken to be the expenditure of the ARC, principally the amount of the funds disbursed to researchers, plus the administrative costs of the Council. We thus ignore the costs incurred on ARC research projects by universities in terms of inputs of research time, grant application costs and infrastructure, and by industry in terms of matching funds under the Linkage Scheme. It is thus implicitly assumed that these research expenditures would have continued in 2003 if the ARC had not funded any research in that year, though not necessarily delivering the same level of research outcomes.

In modelling a hypothetical hiatus of ARC operations during the year 2003, we assume that there would be a reduction in domestically-supplied education in that year, compared with the baseline forecast, of $352 million or 1.36 per cent[98]. It is further assumed that the rate of a general consumption tax varies in order to leave the public debt-to-GDP ratio unaffected by a hypothetical cessation of ARC operations.

In order to conduct the simulations it was necessary to obtain estimates of the productivity benefits to Australia from ARC research undertaken in 2003. These estimates were supplied to us by Allen Consulting. It considers that the research will lead to productivity increases in three separate stages. Allen estimates that the first productivity effects of the 2003 research will emerge in 2007, with subsequent productivity improvements in 2011 and 2013.

For 2007 Allen Consulting indicated that the research will result in benefits equivalent to 12.5 per cent of the research cost computed in real terms[99]. This resulted in a productivity shock of 0.00513 per cent. It was assumed that for the period modelled there would be no depreciation in the stock of knowledge generated by the ARC research and thus primary-factor productivity is assumed to remain 0.00513 per cent above the no-2003-ARC forecast for the 11 years following 2007.

For 2011 Allen indicated that there would be a further economy-wide productivity increase, equivalent to a benefit of 13.5 per cent of the 2003 research expenditure. This translated into a further productivity boost of 0.00494 per cent[100]. Again, this new productivity effect is assumed to remain throughout the forecast period.

[98] Virtually all expenditure (over 99 per cent) on education by Australian governments is on education supplied from domestic sources.

[99] We applied this percentage just to the dollar value of the research funding (in 2007 prices). That is we excluded from the amount on which the return was computed the costs of administering the ARC program. These administration costs were assumed to be 4 per cent of program costs.

[100] It will be noticed that although the percentage benefit provided by Allen is slightly higher for 2011 than 2007, the productivity effect is marginally lower. This is because the dollar benefit is being divided by a higher level of real GDP.

The final pay-off from the 2003 ARC-funded research is estimated by Allen Consulting to occur in 2013, with the estimated benefit being 13 per cent (in real terms) of the original research expenditure. However, Allen considers that this final productivity boost will occur only in a limited number of sectors of the economy. We confined the productivity shock to the 17 Monash industries that make up the Metal Product Manufacturing, Machinery & Equipment Manufacturing and the Communication Services sectors. Primary factor productivity was computed as increasing by 0.114 per cent in each of these industries.

The simulations reported here are for a single year of research within an on-going research funding structure. It is important therefore not to incorporate adjustment costs that would relate to a one-off funding change. Thus we assume that the level of Australian employment is unaffected by the change to education funding (and subsequent productivity boosts), with the real (post-tax) consumer wage adjusting to accommodate this.

4. Simulation Results

Figures 1 to 3 show the macroeconomic effects of ARC-funded research undertaken in 2003.

It can be seen from Figure 1 that, in accordance with our assumptions, the decision to undertake ARC operations in 2003 does not have any direct effect on productivity growth until 2007[101]. Thus the economy suffers from negative effects associated with the funding of the research in 2003. However, these negative effects quickly dissipate in subsequent years and as the first positive impacts on productivity start to occur in 2007, real GDP exhibits in that year a positive deviation from the no-2003-ARC case.

The initial negative impact on the real wage can be explained through a simple back-of-the-envelope (bote) model.

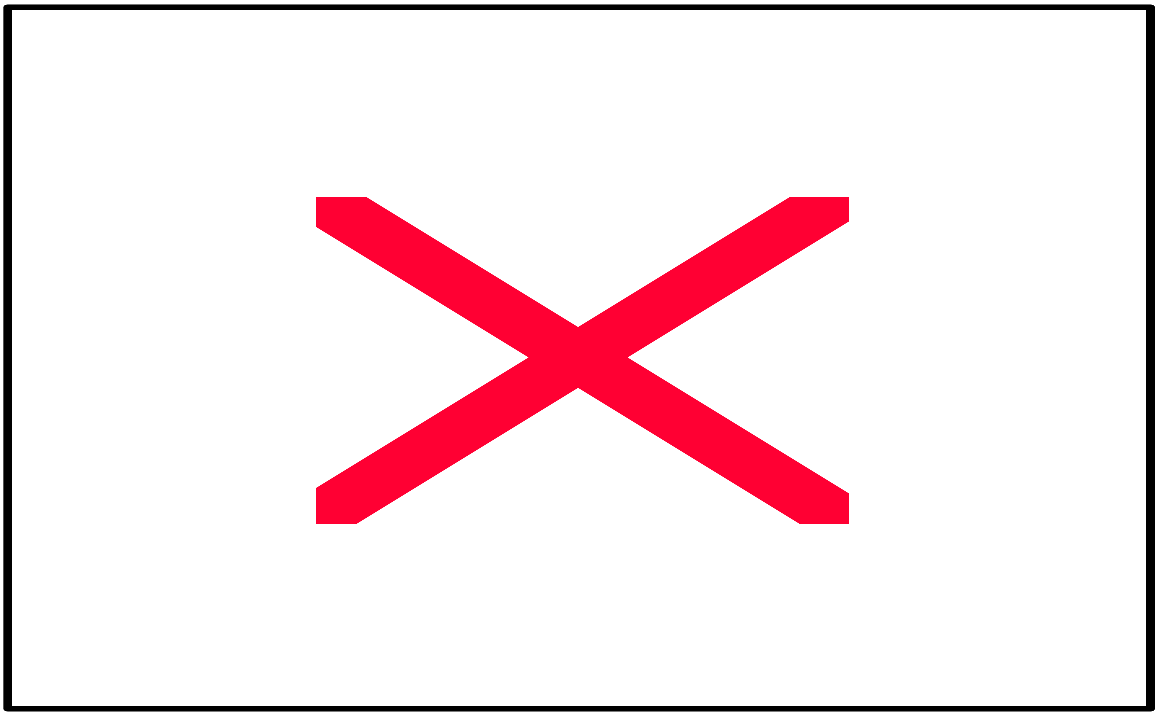
We start with a production function for the economy:

$$Y = AF(K, L) \qquad (1)$$

where Y is output (GDP), A is a technological coefficient, and K and L are capital and labour inputs respectively.

[101] Figure 1 does show an extremely small negative effect on economy-wide productivity during 2003 to 2005. This is caused by indirect effects on the composition of the economy, as explained shortly.

Figure 1: Impact of 2003 ARC operations on GDP, Capital inputs, the real wage rate and Technology (per cent deviation from forecast with no ARC in 2003)



The representative firm chooses employment so as to equate its marginal product with the real wage. Thus:

$$AF_L\left(\frac{K}{L}\right)=\frac{W}{P_g} \qquad (2)$$

where W is the nominal wage and Pg the output price index. Multiplying the numerator and denominator by the consumer price index, Pc, and assuming that consumer prices differ from basic prices only with respect to consumer taxes (i.e. Pc = PgT, where T is the power of the tax), we get:

$$AF_L\left(\frac{K}{L}\right)=\left(\frac{W}{P_c}\right)T \qquad (3)$$

In the first year of the simulation the tax rate increases in order to pay for the 2003 ARC expenditure. However, since technology is not directly affected in 2003 (i.e. A is almost constant) and K (in the short-run) and L are both fixed, the real wage (W/ Pc) must fall. Thus Figure 1 shows the real wage rate deviating negatively from the no-2003-ARC case (by almost 0.06 per cent).

It will be noticed that there is a slight negative deviation in GDP in 2003. This is due to (measured) productivity growth in the provision of Education being lower in the baseline forecast that the industries that are negatively affected by the tax rise. This indirect (dynamic) effect, as well as lowering GDP (via equation (1)), also requires a slightly greater reduction in the real wage (see equation (3)).

In order to understand the movement in other key macroeconomic variables we further develop our bote model. Equation (4) is the standard condition that the marginal product of capital is set equal to the real rental rate.

Finally equation (5) is the GDP identity.

$$Y = C + I + G + (X - M) \qquad (5)$$

Looking at equation (4), we would expect little change in the rental rate of capital, since the capital/labour ratio is fixed, as to for all intents and purposes is A. Thus we would expect investment to virtually be unaffected by the expenditure on the ARC. However, looking at Figure 2 we see that real investment is expected to undergo a relatively large negative deviation (-0.17 per cent) in 2003. We now proceed to uncover the reason for this.

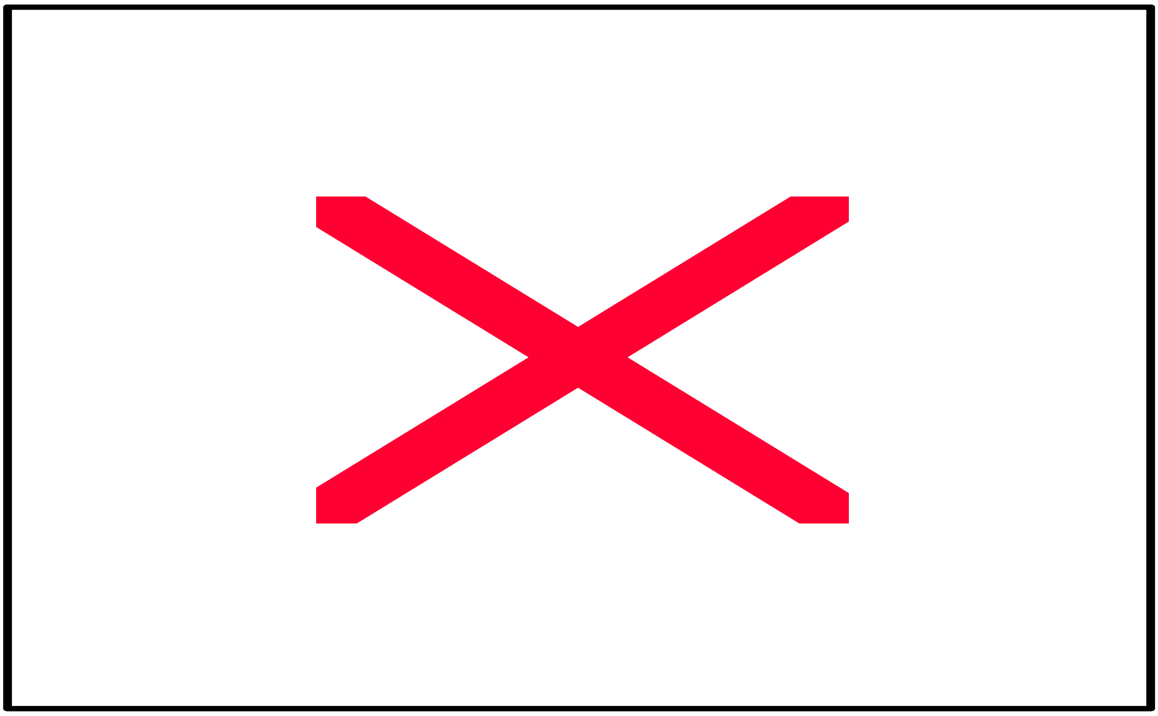
It should be first noted that investment can be expected to be a function of the rate of return on capital which is not exactly the same as the real rental rate. Multiplying the right hand side of (4) by _ / _ (where _ is the cost of installing a unit of capital), we get:

$$\left(\frac{Q}{P_g}\right) = \left(\frac{Q}{\Pi}\right)\left(\frac{\Pi}{P_g}\right)$$

First look at the rightmost term in brackets. We might expect that (since the capital price index covers some imported, as well as domestic products, and the GDP price index covers some export, as well as domestic, goods) with a decrease in the terms of trade (implied by the positive deviation in exports; see Figure 3) this term might increase. This in turn would imply a fall in the rate of return on capital (Q/_) and thus a fall in investment. However, it turns out that the capital goods index price falls by 0.09 per cent compared with a decline in the GDP price index of only 0.03 per cent. The reason for this is the switch in expenditure towards labour-intensive education and away from more capital-intensive consumer goods (which includes, in particular, a large share of housing). Lower demand for capital goods reduces their price, and of itself increases the rate of return, by the above argument. However, the compositional effect on investment outweighs any stimulus to investment via the rate of return. That is, the squeezing out of more capital-intensive industries by the increased educational expenditure directly leads to the fall in investment.

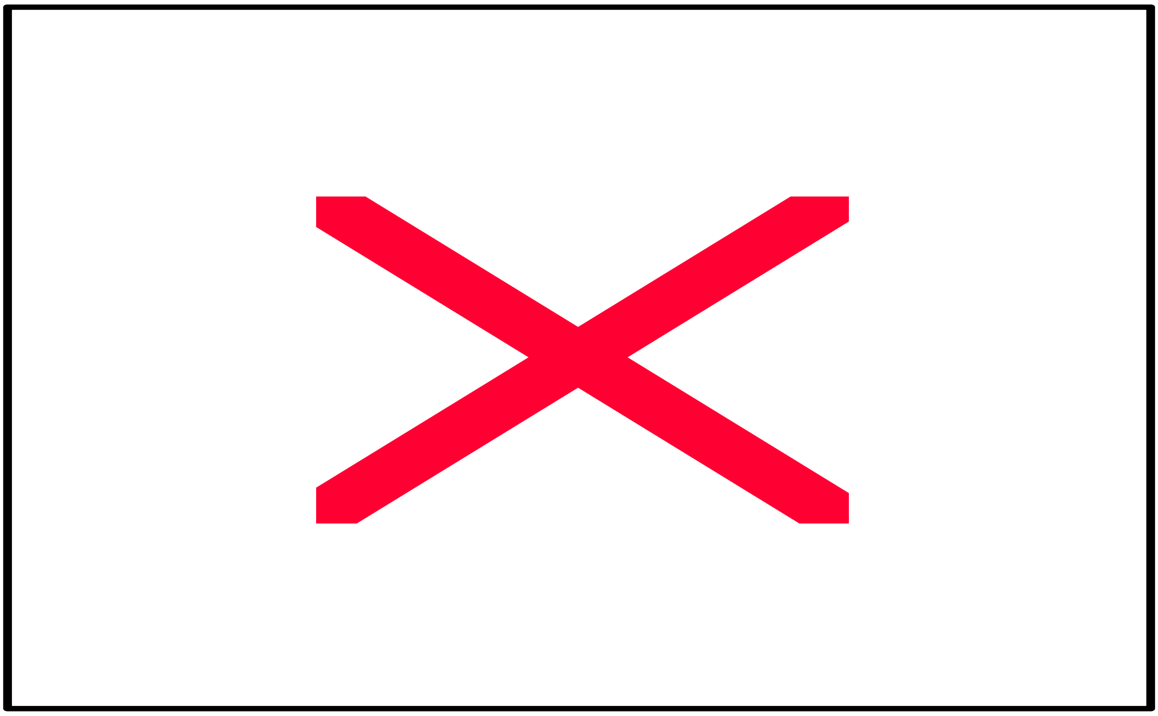
The fall in real consumption in dollar terms is about 15 per cent greater than the increase in government (education) expenditure. The difference is due to a negative deviation in GDP in 2003 of about $50 million (see Table 1). Since real investment falls by around $200 million, there must be an increase in net exports, in order that the GDP identity holds (see equation (5)). As can be seen from Figure 3, this is accomplished by a depreciation of the real exchange rate.

Figure 2: Impact of post-2002 ARC on the Real Consumption and Investment (per cent deviation from forecast with no ARC beyond 2002)



In 2004 educational expenditure returns to its baseline forecast value for that year. The economy thus returns towards the basecase, although capital adjusts slowly. In 2007, the economy receives the first productivity benefits of the 2003 ARC research. . We now consider the results for 2007 and subsequent years. In 2007 all primary-factor-saving productivity is estimated to improve by 0.00513 per cent as a result of the 2003 ARC-funded research. In terms of our bote model this causes an increase in the value of the variable, A. With tax rates not directly affected by the productivity shock and the capital-labour ratio held fixed, the real wage must rise via equation (3).

Figure 3: Impact of 2003 ARC on Aggregate Export and Import Volumes and the Real Exchange Rate (per cent deviation from no ARC operations in 2003 forecast)



Thus in Figure 1 we see the real wage beginning to positively deviate from the baseline from 2007 onwards. GDP increases via equation (1) while the real rental rate of capital increases via equation (4), thus causing an increase in real investment[102]. Real consumption rises in line with the GDP increase while net exports fall slightly to allow the increased investment to be funded via foreign borrowing.

The above effects continue through the forecast period, being further accentuated by the positive productivity shocks of 2011 and 2013.

5. Summary of key simulation findings

Table 1 shows the results for the components of GDP and employment in terms of amounts of the deviations (in $m) rather than in the percentage deviation terms that are provided in Figures 1 to 3.

[102] Investment is already above the baseline in 2004 through 2006 in order to return capital stocks towards the basecase.

Table 1: Impact of ARC 2003 operations on Australian Macroeconomic Variables (Deviation from forecast with no ARC operations in 2003, in $m*)

	2003	2004	2005	2006	2007	2008	2009	2010
Real consumption	-405	-18	4	0	34	36	39	41
Real investment	-204	14	15	14	26	25	24	22
Export volumes	96	-24	-32	-23	-13	-8	-3	1
Import volumes	-127	1	6	5	18	18	19	19
Real GDP	-47	-37	-27	-23	21	26	31	35
	2011	2012	2013	2014	2015	2016	2017	2018
Real consumption	78	81	130	137	144	152	159	166
Real investment	35	34	60	56	54	53	51	50
Export volumes	15	21	42	56	65	74	82	91
Import volumes	36	37	62	65	69	72	76	80
Real GDP	82	89	159	173	184	195	205	216

*In 2003 prices

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Appendix Three

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