AUSTRALIA'S QUEST FOR THE BIONIC EYE: BARRIERS TO INNOVATION

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This thesis is presented for the degree of Doctor in Philosophy

June 2017

"There is nothing more difficult to plan, more doubtful of success, nor more dangerous to manage than the creation of a new order of things".

Niccolò Machiavelli
The Prince, 1513

Abstract

It is a goal of successive Australian governments to develop an internationally competitive knowledge-based innovation system for the 21st Century. Yet despite the fact that Australia produces its share of the world's scientific articles, in proportion to its population, and the existence of high-profile biomedical success stories such as Resmed's devices for sleep disorders, Cochlear's bionic ear and the Gardasil vaccine against human papillomavirus and cervical cancer, the effectiveness of national innovation is low when compared to other developed countries.

The principle aim of this research is to derive new insight into the complex, often messy process driving the development of Australian biomedical and scientific technologies. While it takes a system-wide theoretical approach, it focuses on the "middle-ground" between fundamental science and final-stage commercialisation, using the bionic eye initiative as an extended case study.

In the first part of the thesis, I review texts and archival documents pertaining to Australia's innovation system policy, keeping in mind the National Innovation Systems framework.

But in order to understand the drivers and dynamics of the system, it is necessary to view innovation from the participants' perspectives. Following ethics approval, I recruited and interviewed 29 participants in the Australian Research Council's Research in Bionic Vision Science and Technology initiative, announced in 2009 and funded over 5 years.

Using this mixed methodology, the study explores the interpersonal, political, cultural and organisational factors influencing innovation, as well as identifying possible points of intervention for governmental policy makers and leaders managing emerging fields of complex scientific and biomedical research. Key recommendations address identified barriers to innovation.

Statement of Candidate

I certify that the work in this thesis entitled "Australia's Quest for the Bionic Eye: Barriers to Innovation" has not been previously submitted for a degree nor has it been submitted as part of requirements for a degree to any other university or institution other than Macquarie University.

I also certify that the thesis is an original piece of research and it has been written by me. Any help and assistance that I have received in my research work and the preparation of the thesis itself have been appropriate acknowledged.

In addition, I certify that all the information sources and literature used area indicated in the thesis.

The research presented in this thesis was approved by the Macquarie University Ethics Review Committee, reference number: 5201300423 on 22 July 2013.

Signature …………………………………..

Full Name: Leigh Dayton

Date: ………………………………………..

Acknowledgements

It goes without saying that at the top of my thank you list must go my supervisors Wendy Rogers, Katrina Hutchison and Lisa Wynn. They were fantastic. They read every word I wrote, made insightful contributions, and guided me masterfully through what can only be described as a very long rite of passage.

I would also like to express my gratitude to friends and colleagues who listened to my ranting about everything from Australia's inefficient innovation system and academic requirements to the sorry state of global politics. Special thanks must go to Janet Green, Estelle Lazer, and Aric Bendorf for reminding me that there is life after a PhD, and to my "cohort buddies" Rebacca Tock and Lanei Alexander for walking the tightrope with me.

As well, I offer a special thank you to Patrick Lesslie who saved the day when my computer crashed about a month before submission, and to Janet Green for the timely loan of a stand-in computer.

Finally, a tip of the hat must go to the many people – especially the participants in my case study --who patiently answered all my questions about the ins and outs of science and innovation in Australia. I hope I have represented your contributions accurately. Without you, I would have been lost.

I began this intellectual journey as a former science journalist, frustrated by Australia's inability to maximise its research expertise. I ended it as doctoral candidate, optimistic that things can change. When we humans stick together, we can make a difference.

Introduction

"There is nothing more difficult to plan, more doubtful of success, nor more dangerous to manage than the creation of a new order of things."

Niccolo Machiavelli, The Prince

In April 2008, newly elected Prime Minister Kevin Rudd held an ideas summit. He invited one thousand prominent Australians of diverse fields to attend the Australia 2020 Summit. Others joined in through local summits held across the country. The task was to "shape a vision for the nation's future" and to discuss ways to meet "future challenges. (Government of Australia, Responding to the Australia 2020 Summit, 2009, pg 1)

The weekend event -- co-chaired by Rudd and Melbourne University Vice-Chancellor Glyn Davis -- generated hundreds of ideas, nine of which were picked up as new initiatives by the Rudd Government. On the list was "research in bionic vision science and technology to support the development of the bionic eye in Australia". Given Australia was "a world leader in bionics'', the implication was the nation would be the first to accomplish the task. (Government of Australia, Responding to the Australia 2020 Summit, 2009, pp 1, 111; Dayton, July 5, 2008)

At the time of the summit I was the Science Writer at *The Australian* newspaper. I covered what in 2009 became the Australian Research Council's (ARC) Research in Bionic Vision Science and Technology initiative, from Rudd's 2008 announcement until late 2012 when I left the paper.

Over those years, I watched and reported as quickly assembled groups competed for funding, as two consortia received grants, as progress within one consortium was dogged by interpersonal disputes. I watched and reported as a US competitor received approval to market its own bionic eye in Europe and the UK in 2011 and in 2013 in the US, shifting the goal post from inventing the first bionic eye to building the best bionic eye. As of mid-2017, neither Australian consortium has moved to Phase 1 clinical trials.

Why? More pointedly, why are cases like bionic eye case all too common? Why does Australia produce its share of the world's scientific articles, in proportion to its population, but fall short on international innovation rankings when compared to other developed countries? This is despite high-profile biomedical success stories such as Resmed's devices for sleep disorders, Cochlear's bionic ear and the Gardasil vaccine against human papillomavirus and cervical cancer. Unfortunately, such successes are few and far between.

This dissertation is my opportunity to answer these questions. In doing so, I have a broad academic goal. I aim to derive new insight into the complex, often messy process driving the development and commercialisation of Australian biomedical technologies.

To that end, my dissertation focusses on the "middle-ground" between fundamental science and final-stage commercialisation, using the bionic eye initiative as an extended case study. In the first part of the thesis, I review texts and archival documents pertaining to Australia's innovation policy. This analysis is informed theoretically by National Innovation Systems framework.

Then in order to understand the drivers and dynamics affecting the system, I explore innovation from the participants' perspectives. Following ethics approval, I recruited and interviewed 29 participants in the Australian Research Council's Research in Bionic Vision Science and Technology initiative, announced in 2009 and funded over 5 years.

Using this mixed methodology, my study explores the interpersonal, political, cultural and organizational factors influencing innovation, as well as identifying possible points of intervention for governmental policy makers and leaders managing emerging fields of complex scientific and biomedical research. Key recommendations address identified barriers to innovation.

The first two chapters of the dissertation provide background information on the concept of innovation and the history of innovation in Australia. In Chapter 1, I focus on the history of the concept of innovation. I define innovation as a complex, iterative, goal-directed process involving players from different organisations who engage with one another in an environment shaped by social economic and political constraints. A critical examination of various models of innovation follows, and I argue that the

National Systems of Innovation model provides the most appropriate intellectual framework for the dissertation.

The history and effectiveness of Australia's national innovation system is discussed in Chapter 2. I argue that the nation's colonial past created an environment in which home-grown scientific and technological advances were valued less than those developed by Britain (the 'Mother Country'), and mineral and resource wealth substituted economically for intellectual productivity. Without the pressure to look beyond the mineral and resource industries for its economic wellbeing, the nation failed to promote its knowledge based expertise. As a consequence, Australia moves into the 21st Century poorly prepared for the challenges of an increasingly global world, one which is increasingly reliant on scientific discovery and application.

From Chapter 3 through Chapter 9 I focus on the case of the bionic eye. Sight is humanity's most powerful sense. Chapter 3 explores the advancing knowledge of the sense, culminating in efforts to build bionic eyes, or visual prostheses. Having established this context, the chapter describes the creation of the bionic eye initiative, based on open source documents. It raises questions about the process of forming and funding two consortia, as well as the organisational and political circumstances in which events took place.

I outline the methodological approach used in this dissertation in Chapter 4. In order to develop a detailed and nuanced understanding of innovation in Australia, it is appropriate to perform a qualitative investigation. Quantitative techniques provide a skeleton for analysis, but cannot tease out the complicated dynamics occurring within Australia's innovation system. Additional use of qualitative methods fleshes out the skeleton with rich personal experience.

As with most historical narratives, the story of Australia's quest for the bionic eye has two versions, official and unofficial. While Chapter 3 tells the official story, Chapter 5 presents the unofficial, off-the-record version pieced together based on information from participants and close observers. This revised account reveals the professional stresses and interpersonal strains of working within the fragmented, ever-changing innovation system described in Chapter 2.

The results of my analysis of data obtained through participant interviews are covered in Chapters 6 to 9. Participants came from a range of positions across the national innovation system. They include politicians and policymakers; university and funding body representatives; consultants; and researchers. All the people included in my sample were involved with Australia's bionic vision initiative at critical stages.

In Chapter 6 I discuss the barriers to innovation existing within academe, as observed by participants. What emerges is an account of an environment coloured by interpersonal clashes and incompatibilities. Researchers describe continual competition for scarce funding and ongoing pressure to maintain a strong publication record and grant success. They report that many researchers, or they themselves, hesitate to collaborate with one another in order to build a professional and publication profile in a specific research area. These are key criteria for career advancement.

Chapter 7 shifts to the industry sector. My research identifies a general reluctance of industry experts to collaborate with academic researchers of shared interest. They will put their name to joint applications for federal grants, but do so without enthusiasm and little commitment beyond the minimum of in-kind support. My analysis indicates that this aversion to collaboration with academe derives from key differences between the two groups. These include different measures of success -- publications versus commercial products -- as well as different values, understandings, mutual expectations and patterns of behaviour.

Additionally, Chapter 7 outlines the frequent stumbling blocks which occur when researchers and university administrators interact with politicians and their advisors. My data suggest that most academics do not recognise that the political class seldom has first-hand knowledge of research and development. Instead, they deal daily with the political realities of governing and retaining office. Consequently, communication between academics and time-poor politicians is often ineffective.

Chapter 8 covers my participants' views on the structural barriers to innovation resulting from Australia's 3-year political cycle. Efforts by politicians to appeal to voters and maintain the support of critical constituents encourages short-term thinking about policy, programs and the amount of funding applied to them. Consequently, science and innovation operate in an ever-changing policy and funding environment.

Reported obstacles to effective collaboration arising from Australia's geographic size are discussed in Chapter 9, along with the impact on collaboration of increasingly uncertain career prospects for early and mid-career scientists, and the equally uncertain prospects of late-stage products and processes. Like the structural obstacles examined in Chapter 8, these create an environment in which the cultural clashes presented in Chapters 6 and 7 can escalate, hindering productive collaboration.

In Chapter 10, I offer a mix of policy actions designed to help overcome the cultural, structural, and interpersonal barriers to innovation. These actions target the national innovation system as a whole, not just components of it which is often the case in expert analyses. In developing my recommendations, I draw on my review of relevant literature, from academic analyses to government and stakeholder reports.

Most importantly, I draw on my detailed case analysis of Australia's bionic vision initiative. The rich data drawn from participant interviews bears out in a compelling way both the importance of taking policy action, and the relevance of the specific recommendations I make. I present these recommendations in thematic groups based on the themes arising from participant interviews: Continuity, Funding, Collaboration, and Translation.

It can be argued that my recommendations are a wish list, that they are proposed as solutions to problems that are complex, as well as historically, structurally, culturally, and politically driven. While this is true, each recommendation rests on a solid framework of existing scholarship, enriched by the direct experiences of my case study participants, and contains information which may assist implementation.

For example, I identify possible points of intervention for governmental policy makers and leaders engaged in managing, supporting or investigating the emerging fields of complex scientific and biomedical research. As well, I indicate where further work is required and where ideas could be tried and assessed through a rigorous review processes.

Taken together, I argue these recommendations form a mix of policies with the potential to attract bipartisan political support, contribute to innovation scholarship, and, if adopted, boost the effectiveness of Australia's innovation system as a whole.

Change is possible.

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List of Abbreviations

AAS	Australian Academy of Science
ACOLA	Australian Council of Learned Academies
AIG	Australian Industry Group
ARC	Australian Research Council
ASIC	Australian Securities and Investments Commission
ASMR	Australian Society for Medical Research
BEI	Bionic Ear Institute
BERD	Business Expenditure on R&D
BVA	Bionic Vision Australia
CERA	Centre for Eye Research Australia
CRC	Cooperative Research Centre
CSIR	Council for Scientific and Industrial Research
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSL	Commonwealth Serum Laboratories
ECR	Early career researcher
EMC	Early and mid-career
ERA	Excellence in Research for Australia
FDA	Food and Drug Administration
GDP	Gross Domestic Product
GERD	Gross Domestic Expenditure on R&D
GII	Global Innovation Index
INSEAD	Current name for Institut Européen d'Administration des Affaires
IP	intellectual property
iPSC	Induced pluripotent stem cells [NB it really is lower case i]
ISA	Innovation and Science Australia
MD	Age-related macular degeneration
MIT	Massachusetts Institute of Technology
MU	Melbourne University
MVG	Monash Vision Group
NHMRC	National Health and Medical Research Council
NICTA	National Information and communication technology Australia
NIS	National innovation system or systems

NISA	National Innovation and Science Agenda
NIH	National Institutes of Health
OECD	Organisation for Economic Co-operation and Development
PMSEIC	Prime Minister's Science, Engineering and Innovation Council
POW	Prince of Wales
QUT	Queensland University of Technology
R&D	Research & Development
RBG	Research Block Grant
RP	Retinitis pigmentosa
SBIR	Small Business Innovation Research
SBRI	Small Business Research Initiative
SI	Systems of innovation
SME	Small to medium enterprise
SRI	Special Research Initiative
TGA	Therapeutic Goods Administration
USC	University of Southern California
UNSW	University of New South Wales
WHO	World Health Organization
WIPO	World Intellectual Property Organization

Introduction

Innovation is the complex process by which an invention is devised and translated into a commercialised product or procedure. It is, broadly speaking, the subject of this thesis in which I investigate the process of innovation in Australia using the government-initiated bionic eye project as a case study.

Specifically, I focus on the “middle ground” of the innovation process -- the period between the initial idea and commercialisation -- because it is a relatively neglected area in Australian federal policy development and analysis. In contrast, there is a greater body of policy addressing the early stages of innovation – the creative spark and funding of basic research – and the end of the process, commercialisation.

The principle aim of this research is to derive new insight into the complex, often messy process that is innovation in Australia. Despite its internationally respected fundamental and applied science, the country has a poor track record of commercialising potential products and processes when compared with comparable nations.

To determine why this is the case, in this thesis I conduct a “diagnostic analysis” of Australia’s innovation system, seeking to identify the barriers to innovation. To derive my data, I use a mixed methodology. That is, I combine expert commentary and analysis, policy documents and academic literature about Australia’s innovation system with a qualitative study of the bionic eye initiative.

This approach is derived from the National Innovation Systems (NIS) framework which has gained increasing support with international innovation scholars over the last thirty years. The framework takes a system-wide view of an innovation system to assess the interaction between its component parts, human and structural.

I present the results of my work as follows. Chapter 1: *The Concept of Innovation*, discusses just that -- the concept of innovation, what it is and how it is investigated by scholars using the NIS framework. I also introduce how I use the framework to conduct a diagnostic analysis of Australia’s national innovation system, focussing on the interpersonal, political, cultural, and organisational factors influencing the barriers to innovation.

In Chapter 2, *Innovation in Australia*, I review relevant policy documents, reports and other texts, as well as international assessments of Australia's ranking on various measures of innovation success. The chapter describes the cultural, economic and political forces which shaped, and continue to shape, the nation's ability to conduct internationally respected research, as well as its comparative inability to effectively commercialise potentially successful products and processes derived from the research.

Chapter 3: *The Bionic Eye* covers the emergence and evolution of a technological solution to blindness: the bionic eye. Additionally, the chapter traces the origin, implementation and outcome of the Australian Research Council's Research in Bionic Vision Science and Technology initiative – the bionic eye initiative.

I describe the methods used for my empirical qualitative study of the bionic eye initiative in Chapter 4: *Methodology.* Specifically, I follow the Reporting Qualitative Research (COREQ) checklist (Tong, Sainsbury, & Craig, 2007). Findings based on this methodology build on the textual data presented in chapter 3.

I present my findings from the participant interviews in chapters 5-9. Chapter 5: *The Revised History*, combines data from the interviews with that from scholarly texts and expert commentary. It fleshes out the 'official' story of the bionic eye initiative. Chapters 6-9 present findings from the participant interviews as follows:

- Chapter 6: *Academic Culture,* covers barriers to innovation within the university-based research sector. Issues surrounding funding, metrics and isolation are critical.

- Chapter 7: *Culture Clash: The Influence of Industry and Political Cultures,* addresses barriers to innovation triggered by the different values, common understandings, mutual expectations and patterns of behaviour between the industry and political sectors.

- Chapter 8: *Structural Barriers: Politics and Funding,* describes key barriers to innovation, derived from the structure of Australia's political system. The 3-year political cycle and funding play a significant role.

- Chapter 9: *Structural Barriers: Geography, People and the Valley of Death,* presents further findings triggered by the structure of the national innovation system. Participants highlighted the fact that Australia has a small population spread across a large land mass as a significant barrier. They identified weaknesses in the scientific and industrial 'talent pool', and noted systemic barriers affecting the gap between laboratory research and the marketplace.

I present my recommendations in chapter 10. They target the national innovation system as a whole rather than as isolated components, and include a mix of system-wide solutions targeting the barriers identified in the previous chapters. I present my recommendations under four themes which emerged from my overall analysis: Continuity, Funding, Collaboration, and Translation.

Finally, in Chapter 11: *Conclusion,* I pull together what I see as the implications of my work, and reflect on its strengths and weaknesses.

What remains now is hope and challenge. I hope my work contributes to efforts by participants across the innovation system to boost Australia's innovation success. I recognise, however, that doing so poses a challenge. The barriers ahead are complex, not to mention historically, structurally, culturally, and politically driven. To reprise the quote from Niccolo Machiavelli I cited at the beginning of this thesis, "There is nothing more difficult to plan, more doubtful of success, nor more dangerous to manage than the creation of a new order of things".

Machiavelli's advice to his prince is correct. Still, change is possible. Each of my recommendations rests on a solid framework of existing scholarship and is enriched by the direct experiences of the bionic eye case study participants. As well, each recommendation notes where further work is required and where ideas could be tried and assessed through a rigorous review processes.

Individual recommendations also identify possible points of intervention for governmental policy makers and leaders engaged in managing, supporting or investigating the emerging fields of complex scientific and biomedical research. Taken together, I argue these recommendations form a mix of policies with the potential to attract bipartisan political support and, if adopted, to boost the effectiveness of Australia's innovation system as a whole.

In conclusion, I offer this thesis as my contribution to the intellectual effort to increase successful innovation in Australia.

Chapter 1: The Concept of Innovation

What is innovation?

IN May 1796 British physician Edward Jenner found a young dairy maid, Sarah Nelms, who had fresh cowpox lesions on her hands and arms. He collected material from her and used it to inoculate 8-year-old James Phipps. The boy got mildly sick. In July Jenner inoculated James with smallpox. The child remained healthy. For Jenner, this was evidence that his hypothesis was correct: cowpox infection protects against smallpox (Riedel, 2005, p. 24).

Jenner's "experiment" is a classic example of innovation of the day. The Gloucestershire physician and scientist built on a previous medical procedure -- inoculation with smallpox, a process called variolation. He then trialled the new approach, which he called vaccination, with other volunteers and eventually conducted a nationwide survey, comparing the resistance to smallpox of vaccinated and variolated people. While he did not seek to enrich himself, he distributed his vaccines to anyone who requested it. Gradually, vaccination replaced variolation which was outlawed in England in 1840 (Riedel, 2005, pp. 24–25).

Throughout the century other inventions, medical and scientific, occurred which today are taken for granted: from the battery (1800), the electric lamp (1809), stethoscope (1819), antiseptics (1847) and pasteurisation (1856), to the locomotive (1814), Portland cement (1824) and the internal combustion engine (1858). Toilet paper followed (1893), then the zipper (1893), and to greet the turn of the century, instant coffee (1909).[1]

The process of 'innovation', the creation and distribution of 'inventions' such as the internal combustion and the stethoscope, is clearly central to human health, wealth and well-being. Yet despite its obvious importance, the phenomenon only began to receive sustained scholarly attention in the 1960s. Interest rapidly grew, however, and today innovation studies are proliferating (Fagerberg, 2003, p. 2). A search for "innovation" on the SCOPUS database, for example, turns up 93,064 results.

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[1] For an entertaining and informative list of Industrial Revolution inventions see: http://www.timetoast.com/timelines/inventions-of-the-industrial-revolution-1800-1920.

Although the sheer number of publications is high, the innovation literature is highly fragmented. “Innovation” appears as a scattergun term, used primarily in studies of a range of industries, from agriculture, aviation, engineering, criminology, hospital management and telecommunications to wind energy and medical devices and procedures. The vast sweep of research on innovation “spans disciplines and levels of analysis,” write Canadian researchers Greg Sears and Vishwanath Baba of the “voluminous literature” (2011, p. 357).

Although they summarised the piecemeal nature of research into the nature and dynamics of innovation nearly thirty years ago, the view of Stanford University colleagues engineer Stephan Klein and economist Nathan Rosenberg remains surprisingly fresh. Back then they claimed that innovation as a scholarly field was quite new and suffered from an “overabundance” of specialised comment and a lack of integrated, mature viewpoints in the literature (Kline & Rosenberg, 1986, p. 302).

That remains the case today. If innovation were a mature scholarly field there would be both general theories and specific applications of those theories to fields like medicine. Such theories are lacking in the current literature. Further, disciplines as diverse as economics and sociology study innovation, and do so from different perspectives. Cases in point: computer experts create innovation networks, bioethicists tackle innovation law, and sociologists ask how they can identify perceptual aspects of innovation.[2]

This diversity of innovation research derives from its history as a concept and the history of technology itself. A recently as the 19th century, innovation as understood today did not occur. Instead, early inventions were primarily the work of solitary individuals such as Jenner.

According to Kline and Rosenberg, these people sought to solve a specific problem -- for instance, creating an instrument for listening to the heart or an improvement in a product or process -- as Jenner did with his invention of vaccination. Successful inventors gained significant competitive advantage, although they did not necessarily establish a business or deal directly with one. Everyday business and production was conducted primarily in crafts or guilds.

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[2] Gilbert, Pyka and Ahrweiler (2001) discuss computer simulations of innovation networks. J. A. Robertson (2010) links innovation, law and science from a bioethical perspective, and Collyer (2011) tackles sociological methodology used to study innovation.

Industrialisation was under way in the 18th century, but by the early 20th century the shift from the craft shop to the factory floor was in full swing. Similarly, the process of creating inventions was being organised by entrepreneurs into a process involving many people employed in a business. As noted by Kline and Rosenberg, this reflected the cost of "staying even" in the highly competitive marketplace (1986, pp. 276–277, 292–293, 302–303).

Austrian American economist Joseph Schumpeter (8 February 1883 – 8 January 1950) observed the change. He was the first scholar to propose that the process of innovation – not the invention itself -- is the critical dimension of economic change at the national level. For Schumpeter (1936), the vehicle of that change was the entrepreneur and the firm.

According to British economist Mark Blaug, Schumpeter was among a group of British and European thinkers --including Knut Wicksell, Arthur Cecil Pigou, Karl Marx and David Ricardo -- who focussed on the problem of classifying innovations[3] for analytical purposes. They sought to use the classifications to help describe the wealth-generating mechanism of innovation (Blaug, 1963, p. 14).

In his earlier work Schumpeter classified innovations, that is inventions, according to type: new products, new methods of production, new sources of supply, exploitation of new markets and new ways of organising business to save labour costs and capital. Schumpeter intended the classifications to be part of a theory of innovation and entrepreneurship which, in turn, he envisioned would ultimately develop into a general theory of economic development (Blaug, 1963, p. 14; Fagerberg, 2003, p. 5; Lambooy, 2005, p. 1138).[4]

Schumpeter's classification of innovations is fundamental to the emergent understanding of what innovation is – and is not. US management and innovation expert Thomas Robertson claims that later in his career Schumpeter, himself, viewed innovation as distinctly different from invention. For Schumpeter, invention occurred in

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[3] In this context Schumpeter uses "innovation" to mean "invention" as defined later in this chapter.

[4] Schumpeter also classified innovations by how "radical" they are. This Schumpeterian study of the social and economic impact of innovation in the marketplace is one thread of scholarly innovation study, but is not the subject of this thesis which is the innovation process as exemplified by Australia's bionic eye project.

isolation and could or could not be coupled with the process of innovation (T. S. Robertson, 1967, p. 14).

The distinction reflects the difference between craft and factory production. The latter helps make planned, "organised", innovation possible, and, as Schumpeter argued, essential. The scale of factory production allowed entrepreneurs to integrate the creation of inventions, either products or processes, into the enterprise. They could, in essence, organise innovation, pulling together the intellectual and technical expertise within their firm.

Today, the intellectual consensus agrees with late-career Schumpeter. Innovation is not the same as invention. An **invention** is a new contrivance or procedure, potentially subject to patent law. It is often associated with lone inventors and their sudden flash of inspiration. In contrast, **innovation** is the act of creating and making available something new. It is a dynamic process involving multiple people and organisations and which exploits new ideas to generate a new product or process.[5]

This distinction also reflects the recognition that innovation is, as management and marketing experts Lisa Daniel and Patrick Dawson say, a "dynamic social process" involving many contributors. It is not solely the domain of individuals such as Edward Jenner. While the researchers focus on the "integration" of biotechnologies into the wider community, they argue integration is the end state of a "sociological process", one that begins in the research sphere (Daniel & Dawson, 2011, pp. 1–4).

This fits with Kline and Rosenberg who claim that "by definition innovation involves the creation and marketing of the new". Because scholars want to understand Daniel and Dawson's "sociological process", they distinguish between "the new", an invention, and the complex human interactions and networks that precede its arrival on the market, innovation (Kline & Rosenberg, 1986, p. 275).

In other words, as management consultant Peter Drucker states in his 1993 book *Post-Capitalist Society*, innovation is the "application of new knowledge … It requires systematic efforts and a high-degree of organization" (as cited in Johannessen, Olsen, & Olaisen, 1999, p. 123). And T. S. Robertson echoes Machiavelli when he says

[5] Following this definition, individuals working alone are not engaged in the process of innovation. How they create inventions is not the subject of this thesis.

innovation is defined as "a process whereby a new thought, behaviour, or thing is conceived of and brought into reality" -- or not (Robertson (1967) p. 19). The outcome is uncertain.

Regardless of whether the end point is described as "integration" or "commercialisation", or whether the context is the firm, an industry, or a national or international project, leading researchers view the phenomenon as a process. Some sectors of innovation research -- for instance surgical innovation -- may use the term innovation as a noun to apply to new procedures or products in their sector (McCulloch, Cook, Altman, Heneghan, & Diener, 2013, p. 1). But the convention among researchers studying the wider field is to describe the topic of their investigation as innovation.[6] I will follow their example. For my purposes, "innovation" is a process, whereas "invention" is a new product or procedure.

Characteristics of innovation

Since innovation as defined here is a process, it is complex, uncertain, somewhat disorderly and subject to chops, changes and rethinks. That's the case regardless of whether the innovation takes place within a team or between teams, public and/or private (Fagerberg, 2003, p. 6; Kline & Rosenberg, 1986, abstract). While this may seem obvious, there has been a tendency in innovation research to view the process as linear, running from a bright idea to fundamental research, development, commercialisation and, finally, diffusion of a shiny new product or procedure to the market place.

This misrepresents the process according to numerous researchers, among them Daniel and Dawson. Based on evidence from Australia's bioindustry sector they argue the linear approach to innovation is inadequate. It ignores not only technological changes – during and after the innovation process -- but also the networks of stakeholders needed to take a new idea or invention from conception to market. These networks include multiple participants, often from multiple organisations. Participants and organisations may represent diverse personal, governmental and/or commercial commitments,

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[6] Further discussion and examples of the definition of innovation can be found in Daniel & Dawson, 2011, p. 1; Fagerberg, 2003, p. 3; Flagg, Lane & Lockett, 2013, p. 1; Gelijns & Rosenberg, 1994, p. 28; Gilbert, Pyka & Ahrweiler, 2001, p. 1; Johannessen, Olsen & Olaisen, 1999, p. 123; Kline & Rosenberg, 1986, p. 279; Lambooy, 2005, p. 1142; Mytelka & Smith, 2002, p. 1467; Stone & Lane, 2012, p. 1; Swan et al., 2007, p. 529.

objectives and research expectations. Clearly, with so many players and agendas, innovation is inevitably a "dynamic social process" (Daniel & Dawson, 2011, p. 2).

Jacky Swan is a management and innovation specialist at Warwick University's Business School. Along with international colleagues she compared biomedical innovation in the UK and the US. They identified small-scale examples of how this dynamic social process influenced the success or failure of biotechnology projects.

DiagnosticLabs is one example. It was a small US company specialising in diagnostic assays that decided to add therapeutics to the product line. The firm chose a specific disease area for initial development. But despite locating suitable biotech partners, regulatory approval and a solid scientific team the project failed. The reason is that the company's owner decided to sell the company, halting new investment, for reasons that Swan and colleagues did not elaborate (Swan et al., 2007, pp. 537–538).

In contrast, UK firm SampaTech succeeded. Founded by two university scientists to develop novel therapeutics for hepatitis, the firm at first struggled with partners and funding. By eventually finding a chief executive officer with a reputation as a "serial entrepreneurial scientist", SampaTech reassessed its strategy and gained pharmaceutical interest in licensing its lead product (Swan et al., 2007, p. 536).

As these simple examples demonstrate, not only is innovation characterized by complex interpersonal relations – between immediate colleagues and between individuals within different groups -- stakeholders may change their goals, incentives and activities over time (Gelijns & Rosenberg, 1994, p. 28). Obviously, this sea of informal, shifting associations changes the dynamics of the innovation process. The existence of such a personal and professional ebb-and-flow guarantees that innovation is largely unpredictable, patchy and difficult to measure (Kline & Rosenberg, 1986, p. 285).

Since innovation relies on change and is inherently uncertain, it is difficult to plan in detail and difficult to develop and manage effective organisational and national strategies. process. Over the years, economists have developed different approaches, or models, for understanding innovation. But as most are geared to enhancing the wealth-creating capacity of the private sector, they do little to assist the establishment of national innovation policy and projects or to identify possible points of intervention in existing national systems to help them be as effective at achieving their goals as possible.[7] Instead, a systems-oriented approach is required. In upcoming sections I discuss the development of a model suited to the task.

Systems of innovation model

The systems of innovation model (SI) was -- and still is -- used widely both to study and develop innovation systems at the "sectoral" or "regional" level. A **Sectoral SI** focuses on various technology fields, such as information technology, or product areas like pharmaceuticals and surgical instruments (Edquist, 2001, p. 2; Malerba, 2002, p. 2047). A **Regional SI** involves cooperation across regions, within or between countries, and is based on capabilities within the region such as institutions, skills and infrastructure (Doloreux & Pareto, 2004, p.7; Edquist, 2001, p. 2).

Perhaps the most well-known example of sectoral SI is Norway's oil and gas industry. It is built on a mix of public and private funding, development, and ownership, and reflects broad government policy (Gronning, Moen & Olsen, 2008, p. 283). The fact that Norway has now adopted a national approach to innovation shows that sectoral and regional systems operating within the borders of a country can be encompassed by a national innovation system, as discussed below. Like innovation itself, a country's approach to innovation evolves, as do the models developed to understand and enhance it (Mytelka & Smith, 2001, p. 1473).

As noted above, regional SI refers to either geographic areas within countries or parts of different countries which operate together. In-country regional SI often resembles sectoral SI, according to Edquist, because setting the geographical boundaries of a regional system is complicated by the question of which criteria should be used to identify a "region". It could be, for instance, an administrative boundary or a geographical area which suits a particular innovation process or project (Edquist, 2004, pp. 199–200).

The regional SI approach became widespread in Europe in the mid-1990s. The European Commission played a central role in stimulating interest in such cross-boundary systems. Early examples include the Specific Projects Action Line, a regional SI which sought to promote technology transfer across sectors and regions in Europe (Edquist, 2001, p. 2; Mytelka & Smith, 2002, pp. 1467, 1475).

[7] I discuss these models in Appendix 1.

To summarise, the SI model provides observational data which adds to understanding the innovation process. And as the observations are placed within a systemic framework, the approach is useful for planning sectoral or regional innovation projects or policies.

The SI model represents a point in the development of ways of studying and enhancing innovation which began with models developed by economists to boost the wealth-producing capacity of businesses. SI models widened the scope of innovation study and set the stage for the rise of national innovation systems (NIS), which I discuss in the next section. Proponents of the NIS model argue that it is more academically and practically fruitful because it encompasses both regional SIs and sectoral SIs. It brings questions of national priorities and policies directly under national governments.

National innovation systems

In hindsight, the benefits are obvious. But when the state-developed Nordic Mobile Telephony system (NMT 450) began operating in 1981, the Finish conglomerate Nokia showed little interest in the service – the world's first automated cell phone system and the first to allow international roaming. At the time the company made tyres and rubber boots, along with telecommunications equipment such as the Nokia DX 200, a digital switch for telephone exchanges.

It became obvious to Nokia when the Finish government, like Sweden's government, adopted the system as the national standard. Nokia and its Swedish counterpart Ericsson entered the emerging field of mobile telecommunications. As Edquist notes, both governments deliberately used public innovation policy as a "midwife" to assist the birth of the new technological area in the private sector (Edquist, 2001, pp. 6–7; 2011, p. 1734).

Neither company would have assumed the global leadership in the field, he argues, without the adoption by the Finnish government of NMT 450. In Nokia's heyday-- from 1998 when it took over the top spot from Motorola to 2012 when Samsung overtook its lead -- Nokia was the largest maker of mobile phones worldwide (Nokia, 2013; Williamson, 2012). Ericsson focused on telecommunications equipment and on services for mobile and fixed network operators. Despite market down turns, in 2012 Ericsson boasted that 40 percent of the world's mobile traffic passes through its networks and reported sales of USD 33.8 billion (Ericsson, 2013).

The NMT 450 story is illustrative. Firstly, it is an example of government-driven innovation, in this case establishing a regulatory incentive for private industry. More significantly for this thesis, NMT 450 represents the emergence of the national innovation systems (NIS) concept as a framework for both the establishment of national innovation policy and for analysing the complex, evolving and creative process of innovation.

Very simply, the phrase 'national innovation systems' is both descriptive and normative. In the first sense, a NIS is a set of institutions that contribute to the development of a new process or product. In the second sense, governments develop or use these institutions to implement policies or goals designed to influence innovation for social and economic benefit (Sharif, 2006, p. 745).

Moreover, the NIS model is an intellectual tool that can be used to assess the effectiveness of a government-driven innovation system. This kind of analysis looks rigorously at the set of institutions within a system, focussing on critical and variable factors. Among these are the relationships between individuals and groups, the political, social and economic context in which the system operates and the formal structures established to assist the innovation process (Edquist, 2001, p. 13; 2004, p. 182; 2011, p. 1725).[8] I explore these ideas in more depth later in this chapter.

The rise of national innovation systems

The NIS model was a response to neoclassical economics. To borrow from economic theory – specifically from Schumpeter's classification of innovations as "incremental" or "radical" -- the NIS model is radical. It is, also in Schumpeter's words, an example of "creative destruction" (Fagerberg, 2003, p. 5), because the NIS model was a deliberate attempt to break from prevailing neoclassical economic theory. Hong Kong based sociologist Naubahar Sharif goes so far as to claim would be "difficult to overemphasize" the extent to which the NIS concept originated as a "direct attack" on mainstream economics (Sharif, 2006, p. 753).

This intellectual rebellion began in the mid-1980s at Aalborg University in Denmark. At the time, British science policy researcher Christopher Freeman had moved to the

[8] While Edquist is the leading proponent of the NIS model, increasingly, scholars are turning to the model. Among those already cited are Lambooy, Sharif and Fagerberg.

university from the University of Sussex. There, Freeman, who first used the concept "national system of innovation" in 1981, teamed up with economist Bengt-Åke Lundvall who in 1985 referred to the concept "innovation systems" in a booklet[9] [10] (Lundvall, 2007, pg 873).

Both scholars were deeply dissatisfied with what they perceived as the failures of neo-classical economics and its concentration on creating stability, or "equilibrium", within a company or organisation. There is no role for government in innovation, according to mainstream thinking. Freeman and Lundvall argued that by marginalising the role of governments, economic theory had become detached from the realities of the contemporary world in which the market did not -- and could not -- meet all the economic, technological and social needs of society (Sharif, 2006, pp. 753, 757).

Their view was not surprising. At the time, western nations were still smarting from the emergence of Japan as an economically successful and innovative nation. This unsettling phenomenon was the subject of a 1988 book by Freeman[11] in which he introduced the idea of national innovation systems to a wider academic community than had been reached by Lundvall's booklet and his own earlier use of the concept (Sharif, 2006 p. 750).

Then, almost simultaneously, came October 19, 1987. That was the day stock markets crashed, first in Hong Kong, then Europe. Wall Street plunged after other markets had already declined by a significant margin. This "Black Monday" crash – named after the 1929 "Black Thursday" stock market crash that triggered the Great Depression – became "Black Tuesday" for Australia and New Zealand, due to the international dateline.

The plummeting stock markets exacerbated the existing global downturn, caused by the so-called "savings and loan crisis". Between 1980 and 1994 more than 1600 banks insured by the US Federal Deposit Insurance Corporation (FDIC) were closed or

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[9] Product Innovation and User-producer Interaction, published by Aalborg University Press.

[10] In his rigorous but gossipy piece Sharif notes that Lundvall publicly claims he's not the founder of the NIS as is often suggested by other researchers. Lundvall notes that Freeman used the term NIS in an unpublished 1982 paper presented to a working group of the Organisation for Economic Co-operation and Development. Similarly, Freeman gives credit to Lundvall (Sharif, 2006, pp. 750–751).

[11] Freeman, C. (1988). *Technology, policy, and economic performance: Lessons from Japan*. London, UK: Pinter Publishers.

received FDIC financial assistance -- far more than in any other period since the advent of federal deposit insurance in the 1930s (https://www.fdic.gov/).

The impact of the combined crises hit Britain and the European continent. In Scandinavia Finland was especially hard hit, suffering a crisis more severe than the depression of the 1930s (Sharif, 2006, p. 752). Meanwhile, a series of economic crises struck developing nations: Mexico in 1994, East Asia in 1997, Brazil and the Russian Federation in 1999, Turkey in 2000, and Argentina and Uruguay in 2002 (www.worldbank.org/).

This was the highly unstable geopolitical context in which Freeman and Lundvall began work, pulling together not only a novel model of innovation but also their academic and policy colleagues, most of whom were located in Europe and Scandinavia. It was a concept and a tool born of the times and designed to operate within them.

Working with the national innovation systems model

According to Charles Edquist -- a leading proponent of the NIS concept as an academic and policy tool -- the model that Freeman and Lundvall pioneered is the most adaptable and fruitful model of innovation to date. He argues that it contains all the "important" economic, social, political, organizational, institutional and other factors that, together, influence the development and application of innovations (Edquist, 2011, p. 1728).

Moreover, the NIS approach moves away from exclusive examination of actions by organizations or firms, whether public or private, instead zeroing in on collective innovation systems within nation states. It highlights the importance of "systemic connectivity" of elements with the system, and of "deliberate 'intangible' investment" in activities involving institutions within the system, from universities to governments" (Dodgson, Hughes, Foster & Metcalfe, 2011, pg 1145; Patel & Pavitt, 1994, pg 77). It addresses the overall innovation system, set by politicians at the country level to promote the creation of new products or processes (Edquist, 1999, p. 17).

Although the NIS model can be applied to any nation, I suggest it is of greatest relevance to smaller nations such as Finland, Sweden and Australia which deliberately mix government and private participation in the use of new knowledge to create novel processes or products.[12] Smaller countries may also be more flexible administratively, may be more open to new ideas and may have a stronger sense of cultural cohesion and a greater need to innovate to keep up in an increasingly globalised world.

Still, Edquist is the first to acknowledge that the NIS model is not a *theory* of innovation that applies to all situations. He explicitly states that it is an "approach" or a "framework" (Edquist, 2001, p. 3). In fact, there is an ongoing discussion among the NIS community about the need for further empirically-based work to develop the concept into a theory, that is, a formal structure that explains the variables of innovation and predicts outcomes (Edquist, 2004, pp. 485–487).

Regardless, the NIS approach offers a method of assessing the nature and effectiveness of a country's approach to innovation. In the absence of a mature theory of innovation, it provides an intellectual framework which can be used to conduct what Edquist calls a "diagnostic analysis" of an innovation system (Edquist, 2011, p. 1725). An analysis of this type can be applied to an existing innovation system or when developing national policy and projects.

A thorough diagnostic analysis can assist politicians, policy makers and researchers to clarify relations between the broad social, economic and cultural factors that shape innovative activity. It can also help pinpoint innovation-stifling bottlenecks in areas such as skills, research infrastructure and the broader economic infrastructure, as well as in government funding and policy interventions (Fagerberg, 2003, p. 10). Such an analysis, therefore, helps identify what the Organisation for Economic Co-operation and Development (OECD) calls "leverage points" which can be used to enhance performance and competitiveness of the system under review.[13]

Rigorous assessment of specific components – "organisations" and "institutions" – of the system within which innovation occurs is an important feature of any diagnostic analysis (Edquist, 2004, pp. 182–183). Within the NIS model **organisations** are defined as the formal structures, say a governmental department or consortium, which pre-exist

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[12] According to Edquist (1999, p. 3), government intervention is, generally speaking, desirable only when there is an identified failure of the free market and where public intervention may effectively complement market mechanisms. If there is no "problem" to solve there should be no intervention.

[13] See http://oecd.org/sti/inno/thenationalinnovationsystemsphaseiii.htm for a discussion of the objectives of the OECE's National Innovation Systems project.

or are created for a specific purpose. **Institutions** are the sets of implicit or explicit habits, norms, routines or laws that regulate the relations and interactions between individuals, groups and organizations (Daniel & Dawson, 2011, p. 13; Edquist, 2005, p. 182).

Equally important is what happens within the system, what participants in organisations contribute to the innovation process. The objective is to understand how various **activities** change performance within the system and ultimately the system itself. Edquist (2011, pp. 1727–1730, 1750) equates activities with "functions" and "goals" such as gaining knowledge or creating and changing institutions.

The Box below identifies key activities in systems of innovation, including a NIS.

● **Provision of knowledge inputs to the innovation process**

1. Provision of R&D results and, thus, creation of new knowledge, primarily in engineering, medicine and natural sciences.

2. Competence building, for example, through individual learning (educating and training the labor force for innovation and R&D activities) and organizational learning. This includes formal learning as well as informal learning.

• **Demand-side activities**

3. Formation of new product markets.

4. Articulation of new product quality requirements emanating from the demand side.

● **Provision of constituents for System of Innovations**

5. Creating and changing organizations needed for developing new fields of innovation. Examples include enhancing entrepreneurship to create new firms and intrapreneurship to diversify existing firms; and creating new research organizations, policy organizations, etc.

6. Networking through markets and other mechanisms, including interactive learning among different organizations (potentially) involved in the innovation processes. This implies integrating new knowledge elements developed in different spheres of the System of Innovation and coming from outside with elements already available in the innovating firms.

7. Creating and changing institutions for example, patent laws, tax laws, environment and safety regulations, R&D investment routines, cultural norms, etc. that influence innovating organizations and innovation processes by providing incentives for and removing obstacles to innovation.

● **Support services for innovating firms**

8. Incubation activities such as providing access to facilities and administrative support for innovating efforts.

9. Financing of innovation processes and other activities that may facilitate commercialization of knowledge and its adoption.

10. Provision of consultancy services relevant for innovation processes, for example, technology transfer, commercial information, and legal advice.

Source: Edquist 2011

Figure 1: Key activities in systems of innovation

While this discussion is general in nature, the main point is that by viewing a nation's innovation system as a complex and dynamic system -- comprised of structures and people engaged in the creation of new products or procedures – it is possible to assess the effectiveness of the system. This approach borrows qualitative methodologies from the social sciences -- sociology and anthropology, for instance – and quantitative performance measures from economics. Examples of the later include patent data, research and development expenditure and commercial potential.

As Chapter 2 reveals, Australia does not have a coherent national innovation system. The nation's approach is an ever-changing blend of public and private projects and interests. There is no consistent, bipartisan science or innovation policy at the governmental level. This reality does not mean it is neither possible nor desirable to assess Australia's somewhat haphazard innovation process. Although Australia has neither a NIS nor a consistent approach to science policy, I will use elements of the NIS model for two purposes: 1) to conduct a diagnostic analysis of the effectiveness of the country's innovation effort, generally, and 2) to explore the dynamics and effectiveness of the national initiative to develop a bionic eye.

To do so, I will first investigate the "organisations" of the nation's innovation system, its political, research and industry sectors. In later chapters I will probe the nation's "institutions" and "activities", what I collectively call the "cultures"[14] operating within the three sectors. This analytical process involves comparing and contrasting data derived from my qualitative analysis of the bionic eye initiative with data derived from my review of academic papers, expert reports and analyses, as well as government documents and international performance assessments.

The result is a more comprehensive picture of the national innovation system and its interconnected component parts than can be obtained by interrogating either the text-derived data or the qualitative data. Working with this data from a NIS perspective, I seek to reveal how the ad hoc structure of Australia's innovation system impacts and is impacted by the cultures operating within it. The consequence of these interactions is the production and reinforcement of barriers to the nation's ability to take research from the laboratory to the marketplace.

[14] I use 'culture' to mean the values, common understandings, mutual expectations and patterns of behaviour shared by members of a group (Berreman, 1971, p. 544).

My over-riding goal is to add systemic data to the largely sector-oriented evidence base now shaping Australia's innovation policy. I also hope to contribute to the NIS literature by demonstrating that it is possible to learn lessons and gain insights from a failing national system. As Lars Coenen notes, much NIS work builds on the exploration of successful cases such as in Scandinavia and Japan (Coenen, personal communication 2017).

Summary

Today, innovation has gone beyond the days of Edward Jenner and other heroic but solitary players. Electronic devices fit neatly into tiny pockets, imaging equipment watches bodies in action, and surgeons operate on patients in distant towns, even countries, via telemedicine. It's what we as a species do. We tinker, experiment and create something new. We innovate.

Not only do we humans innovate, we think about innovation. And as the sophistication of our products and procedures – our inventions – grows, so too does thought about the process of innovation itself. In this chapter, I've attempted to track the evolution of the concept of innovation as a scholarly field from its beginnings in the early 20th Century. Back then, economists argued that innovation was done by entrepreneurs. Their goal was to maintain corporate – and thus national -- wealth by helping businesses take an idea down the path from conception to commercialisation.

Joseph Schumpeter was the first economist to recognise and analyse the complexity of the innovation process. In so doing, he laid the groundwork for later theoreticians who brought in ideas from disciplines such as engineering, biology and sociology. Models of innovation flourished. But they were piecemeal and, increasingly, divorced from advances in science and the realities of the global economy.

While the field of innovation remains fragmented and no true theory of innovation exists, a small group of academics has pioneered a systems approach to the study of innovation. The national innovation systems model identifies a role for governments in enhancing innovation. Since its emergence over the last three decades, the NIS model has been adopted as a research tool – both to assess specific systems and to understand the determinants and nature of the innovation process – and as a policy tool, helpful for developing national and supra-national innovation systems. To quote Borrás, Fagerberg and Edquist, it is a “new perspective” on science, innovation and policy (Borrás et al., 2011, p. 666).

As noted earlier, I will use elements of the NIS model to conduct a diagnostic analysis of Australia’s innovation system and to guide my investigation and analysis. My goal is to identify critical barriers to Australia’s innovation and ways to enhance the process as the nation moves into the age of complex, multi-disciplinary, multi-national science.

Chapter 2: Innovation in Australia

Introduction

When newly elected Prime Minister Kevin Rudd announced in 2008 that by 2020 Australia would design and build a visual prosthesis, a bionic eye, he initiated an important national research project, one embedded in its own unique context. Like every developed nation, Australia has its own system for managing the innovation process. While the system supports good, often outstanding, science, I argue in this chapter that it is not as productive as it could be, especially when compared to other countries of comparable development. As a result, it is unsurprising that the two Australian collaborations which received federal funding for bionic eye development were both beaten to the market by overseas competitors, as will be discussed in Chapter 3, *The Story of the Bionic Eye*.

In the following sections I describe the development, nature and effectiveness of the country's system for managing innovation. Here, when I refer to Australia's 'innovation system' I am not suggesting that this is in any way similar to the National Innovation Systems (NIS) model, discussed in the previous chapter. That model has been adopted by countries as diverse as Finland, Germany, Switzerland and Singapore. The UK is moving towards such a system, as are various states in the US. Australia is not. Rather, as considered below, Australia's innovation system developed on an ad hoc basis. It was strongly influenced by the nation's colonial history and the emerging political system of state, territory and commonwealth governments.

Similarly, as noted in Chapter 1, there is no consistency in the terminology used by experts and participants to describe an 'innovation system'. Instead, phrases such 'science and innovation system', 'research system', and assorted permutations are used to describe the framework in which Australian innovation occurs. For consistency -- and as it is the subject of my thesis -- I have chosen to use the phrase 'innovation system' as an umbrella term.

Finally, I will use the insights, history and other data from this chapter to help shape my final recommendations, along with findings from my qualitative investigation.

From settlers to scientists

The story of Australia's innovation system begins with individuals, inventors like Henry Sutton who turned their hand to problems, professional and personal, big and small.

Sutton should be Australia's most famous inventor. But not only is Sutton (1856–1912) not famous, most Australians have never heard of the self-taught tinkerer -- despite a remarkable list of accomplishments, including a storage battery, telegraph facsimile, vacuum pump and a long-distance wireless communications system used by the military. Then there is his torpedo which failed to attract funding, a mineral flotation process later developed independently and used widely in the mining industry, and Australia's first hydraulic lift (Dodgson, 2013a).

Sutton was fascinated by horseless carriages. He devised and drove numerous motorcycles and two cars with carburettors he designed himself. He founded the Automobile Club of Victoria, not to mention the state's scientific instrument industry. The list goes on: the world's first portable radio, boasting a range of 500 yards; photographs of the cholera microbe; and the 'telephane', a forerunner to television developed three years before its inventor John Logie Baird was born. Telephones? Hot on the heels of Alexander Graham Bell, Sutton worked on twenty different phones, sixteen of which were patented by others. He even set-up a telephone system for the Ballarat School of Mines where he worked (Dodgson, 2013a).

The director of the Technology and Innovation Management Centre at Queensland University, Mark Dodgson, notes: "Geniuses such as Sutton are a rare breed and dance to their own tune" (Dodgson, 2013a). In Sutton's case that is true both psychologically and historically. In the first instance, Sutton exemplified independent 19th Century inventors, working on their own projects at their own – in Sutton's case, frantic – pace.

Historically, Sutton worked prior to the widespread adoption by Australian business of organised innovation, where entrepreneurs brought together intellectual and technical expertise within their firm to help keep ahead of the competition (Dodgson, 2013a).[15]

If Sutton were working today he would probably be part of a business or national research organisation, one that recognised that getting new products or services to

[15] See Chapter 1, The Concept of Innovation for a discussion of the rise of organised innovation.

market requires more than just a good idea. It requires structure and strategy, as well as collaboration between involved players. It requires recognition that, as covered in Chapter 1, an invention by itself – say a torpedo or a 'telephane' – is not innovation. An Invention is a great idea. In contrast, innovation is the complex, very human process of taking new knowledge and inventions from the laboratory to the market place.

Sutton is an important figure in another sense. His diverse interests followed a transitional moment in history – the 1851 gold rushes in New South Wales and Victoria and later in Queensland and Western Australia. The discovery of alluvial gold heralded the expansion of the Australian colonies' role as a provider of rural commodities such as wool and meat to include supplying mineral resources. It demonstrated that Australia could boom on the back of miners as well as sheep.

Local inventors responded to the technical and communication needs of the rural and the emerging mining industries, as well as the needs of settlers for food, housing, cloth, linen, tableware and other commodities. They modified European technology, for instance the wheat-stripper which was first demonstrated in 1843, or created equipment such as the stump-jump plough, introduced in 1878 and designed to suit Australian conditions (Renew, 1993, pp. 25, 35–36).[16]

It was a time when science and technology met commercial and individual needs, albeit in an ad hoc, inventor-dominated manner. Invention, as distinct from innovation, seldom looked to the future. There was no infrastructure, or imagination, to support what we now call innovation. The country was isolated. Inventors were largely reactive, as illustrated by the advent of the wheat-stripper and the stump-jump plough. And like Sutton himself, inventors were largely isolated with few networks, formal or informal, for exchanging ideas. It was a local world in which the notion of an overseas market for new Australian ideas was as unusual as Sutton himself.

[16] Renew suggests that by 1850 settlers had experienced the colonies' first "boom and bust" economic cycle of a commodity supplier. Following the gold boom, a bust hit in the 1890s, triggering two basic approaches to managing the depression: encouraging growth and employment in manufacturing industries or increasing the quantity and efficiency of production of raw and processed materials. Arguments over the strategies continue into the 21st Century (Renew, 1993, pp. 28, 38–39).

The young nation: From federation to the cold war

In January 1901 Australia's first Governor General -- 40-year-old John Hope, the 7th Earl of Hopetoun – proclaimed the six British colonies of Queensland, New South Wales, Victoria, South Australia, Tasmania and West Australia to be the Commonwealth of Australia. The federation of the colonies was an important milestone, scientifically as well as politically. It demonstrated that collaboration was feasible and desirable. Federation represented a new structure, a new way for the former colonies to work together, one that heralded a new way of applying the tools of science to the development of new ideas and products. The dominance of the individual Sutton-style innovator began to wane.

This fresh, more organised approach to innovation – innovation as a process not a product -- built on changes begun in the 1890s. That's when the Colonial Sugar Refining Company (CSRC) was the first of a handful of organisations to "undertake systematic industrial research and development" (Renew, 1993, p. 41). According to historian Robert Renew company scientists worked to improve sugar yields across all steps of the production process, from cultivation to refining. This integrated, in-house approach laid the Australian foundation for later adoption by business of the organised corporate approach towards innovation which emerged in the 20th Century (Renew, 1993, p. 41),

While the private sector moved towards a more structured and process-oriented approach to innovation, various colonial and later state departments of agriculture also began targeting their scientific effort to the production of useful products for growers, graziers and miners. For instance, the New South Wales (NSW) Department of Agriculture supported scientist William Farrer's efforts to produce a wheat strain suited to Australian soil conditions. Ultimately, Farrer successfully crossed Indian and English wheat varieties, producing in 1903 the appropriately named Federation wheat (Renew, 1993, p. 43).

But of most relevance to this thesis, the newly formed Commonwealth made possible the coordination of money and expertise at a national scale. The shift coincided with a steady rise in the "prestige of organised, professional research and development" (Thompson, Gilding, Spurling, Simpson, & Elsum, 2011, p. 328). The consequence was the real prospect of a national approach toward scientific advance. Commonwealth politicians began to recognise that they could play an important role in the social and economic fortunes of the young nation by supporting its scientists.

Over time, political intervention would lead to the establishment and funding of core components of what would become a national innovation system, albeit one arising in a "haphazard" fashion (Roos & Gupta, 2004, p. 113). Discussed below, these components included the Commonwealth Serum Laboratories (CSL), the National Health and Medical Research Council (NHMRC), and Commonwealth Scientific and Industrial Research Organisation (CSIRO).

The outbreak of World War I triggered the first serious federal venture to harness the emerging values and products of organised science. Clearly, the isolated nation could not afford to rely on overseas supplies of essential blood products and vaccines. In response, it was decided to establish a federal serum institute to meet the nation's needs. So, in 1916 CSL was formed, with bacteriologist William Penfold from Britain's Lister Institute of Preventative Medicine as founding director.[17]

There was virtually no political or scientific disagreement about the founding of CSL, which went on to form the bedrock of Australia's biomedical industry.[18] Nor was there any such dispute about establishment of the NHMRC in 1926 following the recommendation of a Royal Commission, though the Council did not have its first meeting until 1937. Its job was to fund and stimulate research. In 2006 the NHMRC became an independent statutory agency of the federal government.[19]

Such political harmony was not the case with the creation of a national scientific body. As journalist Brad Collis notes in his history of the CSIRO, state-federal bickering about such an agency went on for 25 years. He writes that the new states saw no need for a national research organisation, believing their own agriculture departments and universities could handle their needs (Collis, 2002, p. x). This state-federal tug-of-war did more than slow the development of a national science organisation. The states' self-

[17] For a concise history of CSL see: http://www.csl.com.au/about/history.htm.

[18] CSL was incorporated in 1991 and listed on the Australian Stock Exchange in 1994. Today it is one of Australia's most successful companies with major facilities in Australia, Germany, Switzerland and the US. CSL has over 10,000 employees working in 27 countries.

[19] See https://www.nhmrc.gov.au/about/organisation-overview/history-nhmrc for further details.

interest, together with party politics at the federal level, hampered the development of an effective, globally competitive national innovation system.

Eventually, the bickering over a national research organisation stopped – but only when the 'bugs' bit. A series of insect-borne diseases in the 1920s hit the livestock industry, along with a mysterious condition known as 'coast disease'. Rust was affecting wheat yields, and rising salt was an increasing problem in irrigated parts of the Murray River basin. Agriculture, the nation's prime economic sector, was at risk. A solution was needed. Collis writes: "In May 1925 a conference of leading scientists, businessmen and politicians was convened to determine the most appropriate response" (Collis, 2002, p. x).

The upshot was that in 1926 the CSIRO's predecessor, the Council for Scientific and Industrial Research (CSIR), was created. Its mandate was to develop scientific applications for the advancement of Australian rural industries, and to include a commitment to scientific autonomy and sharing of results. The scope of the organisation gradually expanded to include work in mining, industry, high-technology, defence, and biomedical fields (Collis, 2002, pp. x–xii).

Echoing the research agency's heated birth, a post WWII controversy over classified research versus open and independent science erupted. The US and UK feared CSIR's commitment to scientific autonomy and unfettered international sharing of information[20] would see atomic secrets leaked to Cold War enemies. Buckling under the pressure, in 1947 the Government of Prime Minister Ben Chifley moved all military research from the CSIR to the Weapons Research Establishment, now the Defence, Science and Technology Organisation. In May 1949, Royal Assent was given to legislation restructuring CISR and renaming it CSIRO.[21]

Despite the CSIRO's contentious establishment, the concept of a national scientific research body was firmly established with the Royal Assent. Unfortunately, so too was the tendency for frequent political intervention in the role and objectives of the national

[20] Collis says the chairman of the CSIR at the time, David Rivett, fought vigorously to reinstate the pre-war value of sharing new knowledge freely. Rivett was vilified for his politically unpopular stance. "It made him the target of a concerted smear campaign which effectively ended his career," Collis (2002) writes in the prologue (p. xiii).

[21] Parliamentary debate surrounding the legislation allegedly concentrated on Chifley's alleged "softness on communism", rather than the contents of the bill (Collis, 2002, p. xvii).

scientific effort. If Henry Sutton epitomised the nature of science and innovation in his day, the CSIRO did so in the post-war era and beyond. According to Collis, “with every change of (federal) government the organisation’s role is questioned” (Collis, 2002, p. 479).

Collis’ observation holds true more broadly today. As I show later in this chapter, national science and innovation policy shifts from government to government, often with minimal or no evidence of the need for change and with limited understanding of the role of scientific research in the innovation process.

Lazy days and the baby boom

On February 3, 1954 Queen Elizabeth and Prince Philip stepped ashore in Sydney from the Royal Yacht Britannia. The young monarch symbolised a fresh start from the grim days of World War II.[22] Couples were united, babies born, homes and businesses established, and entrepreneurs and scientists sought to meet the needs and desires of an optimistic and growing society of consumers.

Doug Waterhouse was one of those scientists. During the Second World War, the entomologist invented insect repellents for Allied troops fighting in jungle conditions. Later, as head of the CSIRO’s Entomology Division he continued his work, developing a new product: Aerogard. It became an instant hit thanks to Queen Elizabeth. During her 1963 visit to Canberra Waterhouse arranged for her to be sprayed discretely with the product. When dignitaries and “especially journalists” noticed that while they were besieged by mosquitos the royal party was fly-free, the news went global (Collis, 2002, pp. 43–45; Thompson et al., 2011, p. 328).

In response, Waterhouse received a call from Samuel Taylor, representing the then Australian-owned manufacturer of Mortein insecticide. Waterhouse gave Taylor and company the magic formula. “Back then,” Waterhouse told Collis, “CSIRO policy was to make its discoveries freely available because they had been developed with public funding.” Today, both Aerogard and Mortein are owned by a British-based multinational corporation, Reckitt Benckiser. Waterhouse received a dozen cans of Aerogard for his effort (Collis, 2002, p. 44; Thompson et al., 2011, pp. 328–329).

[22] ABC radio recorded the Queen’s arrival to a “tumultuous” greeting. http://www.abc.net.au/archives/80days/stories/2012/01/19/3411411.htm

In many ways Waterhouse's experience is emblematic of what Lyndal-Joy Thompson and her colleagues call the nation's "routinely casual attitude" towards commercialisation of an invention. They argue that policy makers and entrepreneurs held a "linear" view of innovation which assumed that once a potentially viable product or process was created, development and commercialisation would follow smoothly (Thompson et al., 2011, p. 328).[23] Further, not only were efforts to commercialise products based on unrealistic ideas and hit-or-miss efforts, so too was post-war innovation.

Since the fruits of publicly-funded research[24] were made freely available to the private sector, for instance, many industries did little or no research and development of their own, relying on free intellectual property from the Commonwealth. This pattern continues to be repeated in the sector's current reluctance to invest in research and development, either in-house or in collaboration with public-funded scientists. Industry also relied on tariffs and quotas to protect the products they did produce from higher quality imports. Renew describes such protectionism as "you make it, and I'll protect it" (Renew, 1992, p. 60).

I will discuss these issues further in this and later chapters. Still, it is worth noting here that post-World War II reliance on free research and protectionism did promote infant industries and domestic employment -- but "ultimately stifled innovation" (Green & Roos, 2012, p. 3). The private sector clearly had no incentive to invest in risky though potentially valuable research and development, and much new knowledge and many potentially productive inventions languished or died on the vine.

Moreover, this risk-averse approach to developing and getting new products and processes to market set in train a pattern later highlighted in the 2009 Commonwealth report *An Innovation Agenda for the 21st Century*[25] -- not all new inventions were picked up by the private sector. "Too many Australian inventions and discoveries end up being commercialised overseas, where the value they create is captured by others," the report concludes (Government of Australia, 2009a, p. 3)

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[23] See Appendix 1 for a discussion of innovation theories such as the linear model.

[24] After 1946 Australian universities were expected to conduct original investigations, adding to the stock of intellectual knowledge available to the private sector (Office of the Chief Scientist, 2013, p. 8).

[25] See Appendix 2 for a review of key government reports.

The lack of an integrated and efficient system for supporting the process of innovation, from laboratory to market, is illustrated by the long list of 'lost inventions' documented by Renew and Collis.[26] Perhaps the most famous, or infamous, pre-21st Century example is the 'black box' flight recorder.

When aeronautical chemist David Warren devised the 'red egg', the precursor to the black box, there was no local interest. Australian regulatory authorities and, therefore, businesses, failed to see the value of a device that would help identify what went wrong when a plane crashed by recording cockpit conversations and flight instrument details. However, Warren's prototype was noticed by a visiting former British air Vice-Marshal. It was welcomed by the British Ministry of Aviation and then developed and manufactured first by a British firm. The resulting black box was so successful internationally that in 1965 cockpit voice recorders were mandated in all commercial aircraft built in the US. The world soon followed (Dodgson, 2013a; Renew, 1993, p. 102; Faulkner & Schofield, 2014).

The story of the red egg reflects the times. These were the lazy days of the 1950s, 60s and 70s. Life was prosperous for many Australians. There was no incentive to innovate beyond meeting local needs, and global trade continued to rely on primary products and mineral resources. Business and industry could lean on advances from federally-funded research groups such as CSL and CSIRO and the university sector, while hiding behind a curtain of tariff protection.

Former federal Industry Minister John Button says of the period, private sector performance and investment in research and development was "abysmal by world standards".[27] The bulk of new knowledge and innovations developed by publicly-funded laboratories and, increasingly, by universities languished without an industry partner to commercialise them. The innovation process was halted prematurely.

There was no incentive to change … until the oil shock of the mid-1970s. Demand for Australia's commodities plummeted as the price of crude oil soared in 1973 and 1974.

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[26] Both books are largely up-beat, highlighting the excellent work conducted by Australian inventors and CSIRO scientists. As Collis states, however, much of their work was -- and is -- not taken up in Australia. He writes: "The ideal of the clever country [is] still in sight, but far from assured" (Collis, 2002, p. 479).

[27] Button was speaking to ABC broadcaster Andrew Olle in 1987. Rebroadcast on ABC RN's *The Science Show,* 2 February 2013.

Inflation accelerated in Australia. The government tried to keep inflation in check by reducing the rate of tariffs on most imported goods by 25 per cent, with dire consequences for locally produced products. It was the end of a long boom (Renew, 1993, p. 61).

Banana republic and beyond

"If this Government cannot get the adjustment, get manufacturing going again, and keep moderate wage outcomes and a sensible economic policy, then Australia is basically done for. We will end up being a third-rate economy... a banana republic."

It is May 14, 1986 and Australia's federal treasurer, Paul Keating, is speaking to radio personality John Laws. His "banana republic" warning -- apt but arguably overwrought -- alerted Australians to the profound changes taking place in world trade. New commodities were entering the global market. During the 1980s, to illustrate, the value of trade in manufactured goods increased from half to three-quarters of all goods traded globally. Much of the increase came from "more complex, 'high valued-added' products such as computers, VCRs, cars, machine tools and scientific and medical instruments", all products largely ignored by Australia's private sector (Renew, 1993, p. 65).

Paul Keating's colleague, science minister Barry Jones, summed up the situation succinctly. Australia had "missed the bus"[28] on the revolution in value-added trade and technological innovation. The country continued to import high-tech, high-value goods while the value of its own manufactured products declined.[29] The prevailing view in government and industry at the time had changed little from colonial days -- new technology could be bought or licensed from overseas.[30] Renew notes it is no wonder that, as the 1980s rolled on, many Australian firms failed or were taken over by

[28] Jones' comment from the 1980s was rebroadcast in broadcaster Robyn Williams' introduction to Dodgson's 2013b ABC Radio National series on innovation.

[29] Former federal industry minister John Button makes similar points to Jones. He told Dodgson that in the late 80s Australia processed less than 5 per cent of its wool and that Australian industry was antiquated. Speaking of factories he had visited, Button said: "Some were industrial museums, others industrial-relations bear-pits. I hadn't seen many you want to take a discerning overseas visitor" (Dodgson, 2013b).

[30] There is a striking similarity to the anthropological concept of the 'cargo cult' in which early-contact Melanesian people believed constructing a simple replica of a ship or airplane would attract ancestors bearing European technology and goods (Harris, 1971, pp. 565–568).

international firms. Others, he says, struggled to "catch-up", to improve their capacity to change with the times and to compete in an increasingly globalised market (Renew, 1993, pp. 65, 80).

To put Keating and Jones' comments into context, it is important to note that as Australia entered the 1980s, it was clearly lagging behind overseas competitors in recognising and adapting to the changing circumstances. In contrast, governments worldwide were deregulating aspects of their economies and adopting policies that encouraged business to adopt new ways of thinking and acting. Among such policies were those that fostered the globalisation of the production and distribution of products.

Australia did not begin to tackle its declining economy until the election in 1983 of the Labor government led by Bob Hawke. With "mostly tacit" bipartisan support, his colleagues Keating, Jones and industry minister John Button began a policy shakeup, one that expanded the federal role in science and innovation and in the economic environment in which science and innovation – public and private -- operated. It took time, but the new policies initiated what has been described as the most "radical revision" of the economy since the first decade after Federation (Marsh & Edwards, 2008, p. 12).

On the economic front, import tariffs were reduced and the dollar was floated. Selective industry support programs were downgraded. The tax system was changed and employer-employee negotiations moved from centralised wage-fixing to enterprise bargaining. Parts of the banking system were deregulated, while federal safety and environmental regulations were tightened. In terms of science and innovation policy, the Hawke Government initiated the country's first tax incentives for industrial research and development and promoted a more commercial approach by public research organisations such as CSIRO (Dodgson, 2013b; Renew, 1993, p. 65; Thompson et al. 2011, p. 329).[31]

These changes continued when Keating wrested power from Hawke in 1991, taking over as Prime Minister. The deep recession and high level of unemployment of the early 1990s produced "new opportunities to advance attention to innovation" (Marsh &

[31] The *Science & Industry Research Amendment Act 1986* permitted CSIRO to keep income from work for external organisations and firms without having its federal funding cut (Thompson et al., 2011, p. 329).

Edwards, 2008, p. 13). These included a stronger, more directed role for government in science and innovation than in the days of CSL, the NHMRC and CSIRO. Government involvement continued under the conservative government of John Howard, elected in 1996, albeit with some policy changes.

As the clock ticked toward a new millennium, one thing was obvious: Australia had experienced enormous change since the days when a series of British colonies sent primary goods home to Mother England and inventors like Henry Sutton independently plied their trade. While still predominately a supplier of rural commodities and mining resources, the country had advanced scientifically as well as politically.

The election of Hawke's government in 1983 marked the start of a "transformation" of Australia's economic system, and with it the nation's approach to science and innovation (Marsh & Edwards, 2008, p. 12). Initiatives of the 1980s and 1990s were "broad-ranging" and included efforts to promote public and private collaboration. In recognition of the comparably low level of research conducted by industry, Commonwealth funding of research and development became an "integral part'' of innovation policy (Roos & Gupta, 2004, p. 113).

By the last decades of the twentieth century progress was beginning to be made on the innovation front. New processes improved the efficiency of agriculture and mining. New fields of science emerged, from information technology to biotechnology. And a new approach to science and innovation entered the political discourse, promising to enhance the nation's productivity and role on the world stage. The question was, would it last?

The 21st century

Demonstrating that governments put their own stamp on innovation policy, Prime Minister John Howard greeted the 21st Century with an innovation summit. For three days in February 2000, 550 participants from government, research and business gathered in Melbourne. Initiated by the industry umbrella group Business Council of Australia, the National Innovation Summit was billed as a wide-ranging discussion of "what needs to be done" to boost the pace of innovation (Prime Minister's Science, Engineering and Innovation Council, 1999, p. 1).

By using the summit to reset existing innovation policy, the Howard Government was repeating a persistent pattern of policy change by successive governments. That is so because, despite the apparent engagement of stakeholders, the outcomes had been largely predetermined before participants arrived in Canberra (Marsh & Edwards, 2008, p. 21). "The Summit itself seems to have been a largely decorative activity," write Marsh and Edwards, adding that it was "seemingly designed" to grab industry and media attention and flag the government's commitment. "But there is no evidence that it exercised any substantive influence on policy development" (Marsh & Edwards, 2008, p. 34).

Instead, an appointed "learned group" and the Chief Scientist wrote separate reports both before and after the summit which culminated the following year in the government's innovation policy statement, *Backing Australia's Ability (BAA)* (Government of Australia, 2001). This was followed in 2004 by *Backing Australia's Ability: Building our future through science & innovation*, and in 2006 by the *National Collaborative Research Infrastructure Roadmap*, all during the Howard Government (Marsh & Edwards, 2008, p. 34).

While acknowledging the importance of 'innovation' to the national wellbeing, these reports did not consider the well-established National Innovation Systems (NIS) model discussed in Chapter 1. Instead, they tended to equate innovation with commercialisation and overlooked the need for a strategic and consistent approach to the complex process of innovation. They did, however, attempt to more closely link the nationally-funded research sector with the private sector by establishing new initiatives such as the National Collaborative Research Infrastructure Strategy which continues to this day, albeit with reduced funding.[32]

Subsequent governments (see Figure 2) followed suit, initiating their own reviews, reports and policy statements. While largely accepting the fundamental components of the innovation system that had developed over time[33], such as the CSIRO and the NHMRC, successive governments produced policy statements reflecting their political judgements. New governments ignored, dropped or "rebadged" previous policy, programs and priorities (Green, interview, 14 July 2014).

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[32] I show later in this chapter that these and later efforts to enhance collaboration between government-funded research and industry did not significantly boost innovation.

[33] I discuss the structure of the system later in this section.

1983-1991	**Bob Hawke**	**Labor Government**
1991-1996	**Paul Keating**	**Labor Government**
1996-2007	**John Howard**	**Coalition Government**
2007-2010	**Kevin Rudd**	**Labor Government**
2010-2013	**Julia Gillard**	**Labor Government**
Jun-Sep 2013	**Kevin Rudd**	**Labor Government**
Sep 2013-Sep 2015	**Tony Abbott**	**Coalition Government**
Sep 2015 to present	**Malcolm Turnbull**	**Coalition Government**

Figure 2: Australian governments from 1983

In contrast to the Howard years, the Labour governments of 2007-2013 did seek to build on aspects of initiatives established by the earlier Labour governments of Hawke and Keating. They also attempted a more systematic approach to innovation policy, one more closely resembling the NIS framework. Edquist, for instance, contributed to the *Australian Innovation System Report* 2013, prepared by the second Rudd government. Regardless, while moving positively at the policy framework level, Rudd and Gillard chopped and changed many programs established under Howard, not giving them time to prove their strengths and weaknesses (Green, interview, 2014).

The chop-change cycle began again following Labor's loss in the 2013 federal election. The new conservative Government, led by Tony Abbott, saw a swing to a strong free market focus, involving deep cuts to federally-funded science and the elimination of, or significant funding reductions to, projects designed to promote public-private collaboration. During its tenure in office the Abbott Government released only one science or innovation policy statement, its business-oriented 2014 *Industry, Innovation and Competitiveness Agenda.* Controversially, Abbott failed to appoint a science minister for over a year (Dayton, 2013; 2014; 2015b, pp. 1265–1266).

When Malcolm Turnbull replaced Tony Abbott as Prime Minister in September 2015, he promised to put "innovation and technology"[34] at the centre of his government. Turnbull's signature *National Innovation and Science Agenda* (NISA), released the

[34] To clarify, I define innovation as the process of taking ideas from the laboratory to the marketplace, and see broad categories like 'science' and 'technology' as areas of research which contribute to the process. The organisations in which such research is conducted are part of Australia's 'innovation' system. But in the public discussion of the concepts, definitions vary widely. Turnbull generally defines 'innovation' as 'translation', that is, the process of commercialising late-stage ideas or prototypes.

following December has remained the framework for his government to date.[35] Nonetheless, political pressures shifted the government's attention away from the agenda, what Turnbull had billed as an "ideas boom". To date, NISA remains, although public comments by politicians about the importance of "innovation and technology" are few and far between (Dayton, 2015a; 2015b, p. 6254).

Given the propensity of governments to move the innovation goal posts, it is not surprising that since *Backing Australia's Ability* in 2001 there have been dozens of science and innovation documents, reports and reviews produced by and for Australia's successive Commonwealth governments. "We have far too many reports and too little action," claims Terry Cutler, the Melbourne-based innovation consultant who chaired a 2008 review of Australia's innovation system, *Venturous Australia*. "We don't learn from and are not inspired by what's gone before" (Cutler, interview, 7 July 2014).

For example, of the 72 recommendations in his review, Cutler says only one, dealing with research and development (R&D) taxation, was enacted (Cutler, interview, 7 July 2014). Similarly, Simon McKeon chaired the independent 2013 *Strategic Review into Health & Medical Research*. He is pleased the report was at least publicly released -- many reports are not – but adds: "No government implemented anything from our report, either the Labor government or incoming Liberal government, except possibly the extension of NHMRC grants from 3 to 5 years" (McKeon, interview, 7 July 2014).

"This is not a new problem," states former Australian Chief Scientist, Ian Chubb. "It has been allowed to persist for decades" (Chubb, 2014a, p. 985). Each successive government makes grand announcements and commissions promising reports – but fails to implement recommendations of those reports, and terminates or redesigns programs rather than providing them with sustained funding. Governments promote their own vision instead of identifying and supporting national priorities in a strategic, bipartisan manner. "[Governments] follow whims", says Chubb, adding that Australia is the only country among members of the Organisation for Economic Cooperation and

[35] Note that for logistical reasons, this thesis does not cover changes to government policy or projects after May 2017.

Development (OECD) without a long-term national innovation strategy (Chubb, interview, 16 April 2014).[36]

According to Chubb, Australian policy is, therefore, "the victim of short-term, on again-off again thinking" (Chubb, interview, 16 April 2014). There is no long-term planning or commitment beyond the federal electoral cycle. There is no strategy. The result, as Green points out, is an "incoherent" and "fragmented" approach to innovation. Within this context, the components of Australia's ad hoc innovation system – the organisations, the programs, the players – cannot function efficiently (Green, interview, 14 July 2014).

Below I discuss the structure of Australia's poorly articulated innovation system and then assess its overall effectiveness. The key point of this section is that the innovation policy momentum leading up to the 21st Century stalled and continues to stall (Chubb, 2014a, p. 985; Green, interview, 2014).

The structure of Australia's innovation system

National research organisations such as CSIRO and the Australian Institute of Marine Science are primary elements in the country's innovation system, and the most obvious to observers. However, it is important to note that there are more components to Australia's ad hoc innovation system than national research bodies.

By the turn of the 21st Century, the innovation system had evolved into one with federal government departments at the core, covering areas such as science, higher education, environment and industry. These departments change in name and/or portfolio responsibility, from government to government, often disrupting and fragmenting the management of policies and projects. Around this ever-shifting departmental structure sits is a network of agencies, learned academies and coordinating bodies and advisors, including the Office of the Commonwealth Chief Scientist.

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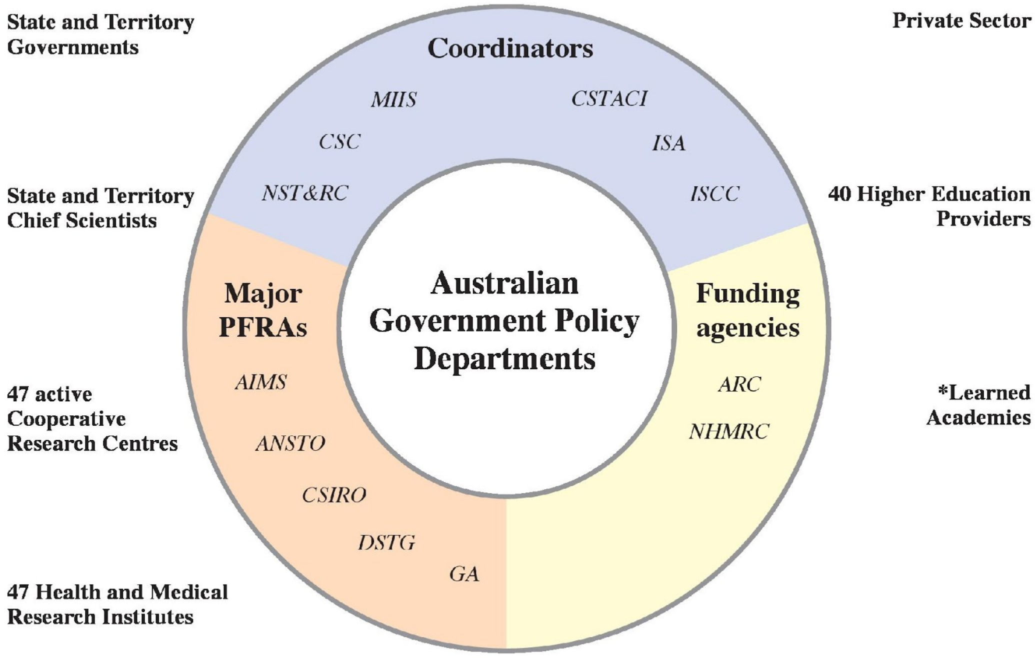
[36] Since my 2014 interview with Chubb, the Turnbull Government in March 2017 released for discussion the *2030 Strategic Plan Issues Paper* addressing "innovation, science and research". See https://www.innovation.gov.au/event/consultations-underway-australias-innovation-plan-2030

AUSTRALIA'S INNOVATION SYSTEM

The interactions between policy makers and decision-makers and the science community are complex. Figure 4 provides a visualisation of the organisation of key actors within the Australian Science System. Government, through departments and funding agencies, provides the funding and support to underpin the science system. Within the system there are numerous science suppliers, including PFRAs, universities, CRCs and H&MRIs, which receive significant amounts of government funding. Government departments also have established formal relationships with coordination bodies and funding agencies.



NST&RC	National Science Technology & Research Council (operational arm of CSC)
CSC	Commonwealth Science Council (chaired by Prime Minister)
MIIS	Ministry of Industry, Innovation & Science
CSTACI	Commonwealth State & Territory Advisory Council on Innovation
ISA	Innovation & Science Australia
ISCC	Innovation & Science Committee of Cabinet (chaired by Prime Minister)
ARC	Australian Research Council
NHMRC	National Health & Medical Research Council
PFRAs	Publicly Funded Research Agencies
AIMS	Australian Institute of Marine Science
ANSTO	Australian Nuclear Science & Technology Organisation
CSIRO	Commonwealth Scientific & Industrial Research Organisation
DSTG	Defence Science and Technology Group
GA	Geoscience Australia

**Learned Academies: Australia Academy of Science, Australian Academy of Technological Sciences & Engineering, The Academy of the Social Sciences in Australia, Australian Academy of THE Humanities*

Sources: ABARES (Australian Bureau of Agricultural & Resource Economics & Sciences) and personal communications.

Figure 3: Australia's innovation system

The Commonwealth provides the bulk of funding and support to the innovation system through collection and redistribution of income and corporate taxes. But as noted earlier, the adversarial nature of Australian politics mitigates against a continuity of priorities, policies and funding. This was noted in many of the 150 submissions to the

2014 Senate Inquiry into Australia's Innovation system.[37] Among these are submissions from the Chief Scientist of Australia, Australian Academy of Science (AAS), Australian Research Council, University of Sydney and more.

While commonwealth funding for innovation may be inconsistent, the six states and two territories lack the power to levy income taxes, but do fund regional innovation projects, primarily through assorted transfer payments from the Commonwealth, philanthropic donations, and industry sponsorship. Amongst the most successful is Queensland's 'Smart State Strategy'. Announced in 1998, the explicit goal was to move beyond reliance on mining and agriculture -- "rocks and crops" -- to develop more and bigger knowledge-based industries (Department of Employment and Training, Queensland, 2005, p. 2).

Operating much like the regional innovation systems discussed in Chapter 1, the Queensland strategy led ultimately to the formation of 36 research institutes, along with three major research institutes[38] at Brisbane's University of Queensland, with connections to industry. By 2012, founding Labor Premier Peter Beattie claimed the strategy had resulted in the commercialisation of 330 products and 23 drugs in clinical development (Wheeler, 2012).

The strategy survived an electoral change to a conservative government, along with reduced federal funding to the university sector. The research facilities and collaborative alliances and networks remained largely intact, and are now administered by another Labor government (Wheeler, 2012). According to Beattie, the reason the concept is "still strong and it's still delivering" is because the research institutes established under the initiative were well-funded and well-established by the time a different government was elected (Beattie, interview, 5 December 2014).

In their detailed analysis of the creation of the strategy, Mark Dodgson and Jonathan Staggs attribute much of the success of the Smart State strategy to "good fortune as much as good planning" (Dodgson & Staggs, 2012, p. 2). Still, the fact that it has (so far) survived two changes in government offers some hope that well-designed long-term

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[37] See http://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Economics/Innovation_System/Submissions for the complete list, including my own (which is attached as Appendix 3).

[38] These include the Translational Research Institute, the Australian Institute for Bioengineering and Nanotechnology, and the Queensland Brain Institute.

strategies can survive the electoral cycle. The good planning involved a strategic assessment of the "opportunities" as well as the "gaps" in Australian science, says Beattie who as opposition leader had visited international innovation centres (Beattie, interview, 5 December 2014).

Despite the good planning, the good fortune arrived in the person of Chuck Feeney, an Irish born philanthropist. Buoyed by previous work with the higher education sectors in Ireland and Vietnam, through his organisation Atlantic Philanthropies, Feeney asked friends such as Australian tennis player Ken Fletcher to be "spotters" for opportunities. Fletcher introduced Feeney to then Brisbane Lord Mayor Jim Sorley and the then Vice Chancellor of the University of Queensland, John Hay, as well as Lawrie Power, then Director of the Queensland Institute for Medical Research (Dodgson & Staggs, 2012, p. 11; Wheeler, 2012).

Backed by the state government, Feeney, Sorley and company kick-started the Smart State strategy with Feeney's $350 million donation to the three University of Queensland institutes (Dodgson & Staggs, 2012, p. 11; Wheeler, 2012). "We funded these institutes [with state, federal, philanthropic and industry funding] and attracted the best brains in the world" (Beattie, interview, 5 December 2014).

One factor in the strategy's success was the profitability of Queensland's mineral and rural resource industries. This helped promote a political environment less sensitive to the 3-year political cycle. Beattie was able to tell colleagues, "There are no votes in this…we're going to see the benefits of this after we're out of office" (Beattie, interview, 5 December 2014). The strategy proceeded as Beattie predicted and remains scientifically and economically successful today. Dodgson and Staggs note that this was an unusual moment in time. In Australia, "political patience is usually brief and political will transient" (Dodgson & Staggs, 2012, pp. 2, 10, 11, 17).

By necessity this section provides only a brief overview of the characteristics of the national innovation system operating today in Australia, together with an example of a regional system. Following sections in this chapter place the national system into its social and economic context and evaluate its effectiveness. Regarding this section, I would like to make three main points:

1. Australia's current innovation system developed in an ad hoc manner.

2. There is no consistent innovation strategy or vision, as successive governments establish their own policies and priorities.
3. The Commonwealth funds the bulk of the nation's research and innovation initiatives, while states occasionally contribute to the development of local initiatives.

4. The Queensland Smart State strategy survives because when it was established it was relatively insulated from the political cycle due, in good part, to the economic position of the state at the time.

Punching below our weight

"Australia punches above its weight," politicians, policymakers and research leaders often claim. To a certain extent this is correct. A 2014 survey published in Thomson Reuters' Web of Science-indexed journals found that in the category of environment and ecology, 17 of the most highly cited researchers in the G20 nations were Australian. The survey also identified 34 researchers in the top 1 per cent by citation in the social sciences, medicine, engineering, materials science and plant and animal science (Hare, 2014; Gaze & Breen, 2014, pp. 10–11).

But since the survey named over 3000 researchers in 20 nations and Australia has nearly 140,000 full-time researchers, that is not quite the impressive showing it seems at first glance. An equal share of the top 1 per cent would give Australia 150 researchers, far more than the 34 identified (Gaze & Breen, 2014, pp. 10–11; Hare, 2014). "Australia's research base is not as outstanding as is popularly imagined," concludes Thomas Barlow an innovation researcher with the US Study Centre in Sydney (Barlow, 2010, p. 1).

Here's another misleading metric frequently identified by Chubb. With just 0.3 per cent of the world's population, Australia produces over 3 per cent of the world's research. But eight countries in the Organisation for Economic Co-operation and Development (OECD) have stronger research-to-population ratios. Ranking ninth in the world, behind comparably developed nations with embedded cultures of research and education, suggests Australia is "middle-of-the-road", Chubb notes. He adds: "Bluntly, we … are not punching above our weight as we so often declare in a fit of misguided and unhelpful enthusiasm" (Chubb, 2014b; Government of Australia, 2013, p. 121).

There are, of course, many ways to measure the effectiveness of Australia's innovation effort. Single numbers seldom tell the full story. A good place to begin, however, is the Global Innovation Index (GII).[39] It is published yearly by Cornell University, the World Intellectual Property Organisation and INSEAD,[40] a graduate business school with campuses in Europe, Asia and the Middle East.

The report is unique in that it measures and ranks the innovation capability and outcomes of 128 countries (2016), using a range of variables: human capital and research, the quality of institutions and infrastructure, market sophistication, business sophistication, knowledge and technology outputs, creative outputs and more.[41] The 2016 index ranks Australia 19th, well behind the leaders. In order, they are Switzerland, Sweden, the UK, USA, and Finland. The earliest index available is 2007. Australia's ranking then was two spots higher at 17th.[42] And 17th is the best showing on the index for all years covered. The lowest ranking was in 2012 when the country ranked 23rd.[43]

As Green points out, breaking down the GII rankings reveals telling inconsistencies in the nation's approach to innovation. When looking at the 2016 *input* side of innovation, Australia ranks 11th for variables such as human capital and research, tertiary enrolments and education, regulatory quality, ease of starting and business and the like. Yet the country's innovation *output* ranks 27th. Worse, in terms of *efficiency* Australia comes in at 73rd place. The implication is that there are significant shortcomings inherent in the Australian innovation system (Green, 2014).

Other international comparisons offer additional insight.[44] It is widely recognised that *collaboration* between business and the research sector increases both wealth and productivity, nationally and at the industry level. Yet the linkages between Australian research and business "are among the worst in the OECD" (Chubb, 2014b, p. 7).

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[39] See https://www.globalinnovationindex.org/gii-2016-report

[40] INSEAD was originally an acronym for the French "Institut Européen d'Administration des Affaires".

[41] For a detailed discussion of the development and methodology of the GII see http://www.globalinnovationindex.org/content.aspx?page=GII-Home

[42] See https://www.globalinnovationindex.org/content.aspx?page=past-reports for the 6 reports prior to 2014.

[43] See http://www.wipo.int/edocs/pubdocs/en/economics/gii/gii_2012.pdf

[44] I discuss these metrics only briefly, as that is sufficient to place Australia's fragmented approach to innovation in the international context.

According to 2014 OECD data,[45] Australia ranked 23rd out of 34 nations on this criterion (Chubb, 2014b, p. 7; Government of Australia, 2013, pp. 53, 116).

Further reflecting the poor collaboration between the research and business sectors, less than one in three Australian researchers work in industry. That is half the OECD average of 60 per cent. In the US four of every five researchers are in the business sector. The UK has a similar distribution of researchers in business as does Australia, but it also has the third highest level of small to medium enterprise (SME) collaboration with the research sector in the OECD. Australia is last on this SME indicator (Chubb, 2014b, p. 8; Government of Australia, 2013, pp. 116–117; Senate Economics References Committee, 2014, p. 2).

And when it comes to a commonly cited innovation metric, patents, Australia makes a poor showing, according to the Thomson Reuters 2014 survey. Australian patent applications originating from Australia -- as opposed to those sought in Australia by overseas entities -- dropped from 7000 in 2003 to just under 6000 in 2012, the most recent data cited in the survey. Over 79 per cent of patents published in 2012 came from outside Australia. The survey authors note, "This indicates a high interest in Australian markets by foreign concerns"[46] (Gaze & Breen, 2014, pp. 12–13).

When Chubb launched his strategy document *Science, Technology, Engineering and Mathematics: Australia's Future*[47] in September 2014, he added to the list of unfavourable statistics about the effectiveness of the nation's innovation system. In 2011 just 1.5 per cent of Australian firms developed products or processes that were new to the world, compared with 10 to 40 per cent in other OECD nations. Fewer than half of Australian businesses identify themselves as 'innovators' (Chubb (2014c).

Chubb continued his commentary regarding the business sector's poor involvement in the process of innovation in his submission to the 2014 Senate Inquiry into the Australian Innovation System. There, he notes that businesses which attempt to "carve a new direction" are stymied by lack of support from a risk-averse financial sector. He

[45] See http://www.oecd.org/innovation/inno/researchanddevelopmentstatisticsrds.htm

[46] Although the question of why Australian-originated patents are so few is not the subject of this thesis. I suggest the 'output' and 'efficiency' deficits identified in the GII are informative.

[47] See http://www.chiefscientist.gov.au/2014/09/professor-chubb-releases-science-technology-engineering-and-mathematics-australias-future/

also cites limited skills in business management, the difficulty accessing global supply chains and poor intellectual property (patenting) strategies (Chief Scientist of Australia, 2014a, p. 2).

Together, factors such as those discussed above contribute to Australia's comparatively poor on showing on the GII. In addition, these factors shape of the contemporary system in which innovative projects such as the Bionic Eye operate. To rephrase the all-important GII finding that when it comes to R&D, Australia is relatively sound on research input but poor on product or process output. To quote Bill Ferris, Chair of Innovation and Science Australia's board, "Australia has internationally competitive 'R' and bugger-all 'D'" (Hartcher, 2014).

Summary

Emerging from its earliest days as a penal colony, the collection of colonies that became Australia served as a mine and a farm for the UK, known then as "Mother England". In return, residents received technology and ideas which were viewed as superior to the home-grown variety. Local inventers like Victoria's Henry Sutton went largely unheralded, and well into the 20th Century scientists such as CSIRO's Doug Waterhouse gave away their work for free. It is a history littered with 'lost' inventions, as the profits from products such as the black box were earned overseas.

Given Australia's mineral wealth and rural commodities, not to mention free access to the fruits of government-funded research, the private sector had little impetus to invest in R&D beyond those traditional sectors until protective tariff barriers began to be dismantled in the wake of the 1970s oil shock. Similarly, there was minimal need to coordinate research efforts nationally, except in times of war or when facing serious rural problems such as the livestock and plant diseases of the 1920s.

Consequently, the elements of the country's innovation system were cobbled together over the years in response to current events and political imperatives of the times. To this day, the system focusses primarily on the research arm of innovation, and does so in the public sector. The private sector is risk averse, particularly when compared to comparable nations, as noted when comparing GII results[48]. Australia's political system, grounded in a 3-year electoral cycle, has hampered efforts to integrate existing

[48] See https://www.globalinnovationindex.org/gii-2016-report#

elements into a coherent national innovation system which effectively links both the public and private spheres and which enjoys the continuity of on-going bipartisan political support. The 3-year electoral cycle also mitigates against development of a long-term innovation strategy, grounded in an evidence-based overview of the country's strengths and weaknesses.

As Australia moves further into the 21st Century, it is poorly prepared for the challenges of an increasingly global world. It is a world in which knowledge-based, high-technology manufactured products form the largest and most profitable share of world trade, pushing mining and rural commodities down the value chain. The nation finds it difficult to innovate. Scholars like Dodgson point to poorly developed capital markets for investing in innovation, the absence of large domestic markets and large high-technology firms, an immature entrepreneurial culture, and badly formulated and directed innovation policies (Dodgson, 2013c).

This is the context in which the Bionic Eye initiative was conceived and developed. In later chapters I will explore how this inadequate innovation system affected the roles, perceptions and performance of the politicians, managers, researchers and business executives who participated in the project across its 5-year lifespan. Results of this analysis provide the intellectual groundwork for the integrated recommendations presented in chapter 10.

Chapter 3: The Bionic Eye

A field is born

Every year *Time* magazine picks the "Best Inventions of the Year". The categories run the gamut from "Wildly Entertaining" to "A Major Deal" and "World-Changing". And 2013 was no exception. Alcoholic coffee (80 proof) was an obvious fit with Wildly Entertaining and the resurrection of embryos using the DNA of Australia's extinct gastric-brooding frog was indeed A Major Deal. And World-Changing? At the top of the list was the Argus II bionic eye.

As an article in *Time* explained: "The Food & Drug Administration approved the first device that can restore partial vision to those who have severe retinitis pigmentosa, which can lead to blindness. The Argus II consists of an implanted artificial retina and a pair of glasses attached to a video unit that enables the patient to see outlines of images and the contrast between light and dark" (25 best inventions of the year 2013, 2013). [49]

While bionic eyes -- technically 'visual prostheses' -- have not yet changed the world, they are definitely changing a field of research that began over 200 years ago during the Enlightenment.[50] The credit goes to polymath and American founding father Benjamin Franklin.[51] He literally sparked the idea that electricity might produce visual sensations of light when -- as legend has it -- during a lightning storm he flew a kite carrying a metal key to prove that electricity and lightning are one and the same[52] (Dobelle, 2000, p. 3; Marg, 1991, p. 428).

Following the kite-key experiment, it became fashionable to hold 'electricity parties'. Guests would form a circle holding hands and then receive a shock from an electrostatic

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[49] The US FDA approved sale of the Argus II Retinal Prosthesis System on 13 February 2013. The company Second Sight gained European approval (CE Mark) for the system in May 2011.

[50] See Appendix 4 for a timeline of important steps in the history of the bionic eye.

[51] Fittingly, Franklin is known as the inventor of bifocals, an early visual prosthesis.

[52] While it is clear that Franklin proposed the kite-key experiment, it's not certain that he was the first to conduct it. Supporting the contention that he was, is a contemporary report by W. Watson: "An account of Mr Benjamin Franklin's treatise, lately published, entitled Experiments and Observations on Electricity, made at Philadelphia in America", *Philosophical Transactions of the Royal Society* London, pp. 202–211, 1751–1752. Science writer Steven Johnson also backs the claim in his 2008 book *The Invention of Air* about Franklin's scientific colleague Joseph Priestly.

charge generator. Franklin is reported to have attended such a party in Paris, noticing that switching the current on and off generated the experience of 'seeing stars', or points of light (Oster, 1970, p. 85).

Indirectly inspired by Franklin's 1751 discovery of electricity, a French animal behaviourist and physician named Charles LeRoy conducted his own experiment, using a borrowed idea. Having heard reports that a 7-year-old English boy had been cured of blindness by an electric shock, the parents of a young man blinded as a result of acute disease approached LeRoy, begging him to shock their adult son, Granger. LeRoy was "skeptical", writes University of California, Berkeley optometrist Elwin Marg. After all, Franklin reported that animals had lost their sight after electric shock.[53]

LeRoy relented. On December 6, 1753 he began treatment, sending electric currents through Granger's head and leg. Despite his patient's "terrible cries", the procedure produced visual sensations of light. Nonetheless, after dozens of shocks on subsequent days "needless to say young Granger remained blind" (Lorach, Marre, Sahel, Benosman, & Picaud, 2013, p. 422; Marg, 1991, pp. 427–428; Sekirnjak et al., 2008, p. 4446; Wagenaar, 2004, p. 1).

According to optometrist and neuroscientist Elwin Marg, other experiments followed. In 1800 Alessandro Volta – the inventor of the battery – wrote to the president of the Royal Society, botanist Joseph Banks, outlining his experiments at the University of Padua which also produced flashes of light. His procedure involved applying current-producing metals, separated by cloth, to the eye or wetted eye lid and either the other eye or the mouth. There is no record of his subject or subjects' response to the procedure.

Other 19th century physiologists carried out similar experiments, but the field quickly shifted to the study of electricity itself. Of most relevance to modern bionic eye research was work conducted with so-called phosphenes, the flashes of light reported by Franklin, LeRoy and Volta. These tiny dots of light are produced by stimuli other than light, for instance a blow to the head, magnetic or electrical stimulation of the brain,

[53] Marg refers to LeRoy's own report on the case in *Histoire de l'Academie Royale des Sciences. Avec les Mémoires de Mathematique & de Physique, 1755*(60), pp. 87–95.

optic nerve or retina.[54] As Franklin observed, sending a high-voltage current through a circle of hand-holding party-goers caused participants to see the flashes (Marg, 1991, pp. 429–431; Wagenaar, 2004, pp. 2–3).

The key value of this early work – steeped more in electricity than in physiology -- is that it moved the notion of restoring vision from the realm of religious miracles onto an intellectual foundation. Since then, research has begun to turn that distant dream to real world reality, demonstrated by the Argus II bionic eye. As discussed later in this chapter, the field of bionic eye research really took off in the second half of the 20th Century, based upon several different approaches to bypassing deficiencies in the visual pathway. But first a look at how human sight works.

The eye, the brain and sight

In the 5th arrondissement of Paris, not far from the Seine, hangs an extraordinary series of six tapestries. Housed in Musée National du Moyen Âge – formerly Musée de Cluny -- La Dame à la Licorne (The Lady and the Unicorn) was created in the late 15th Century. Collectively, the first five tapestries are reportedly an allegory of the five senses: taste, hearing, touch, smell and, of course, sight. The sixth is ambiguous.[55] In contrast, the meaning of La Vue (Sight) is – what else -- transparent. The courtly lady holds a mirror in her right hand while the kneeling unicorn gazes at his reflection. La Vue is an exquisite representation of the most powerful of human senses (Boudet, 1999, pp. 62–63; Michelin, 1985, pp. 115–117).

[54] NASA astronauts Buzz Aldrin and Neil Armstrong reported seeing phosphenes, apparently triggered by cosmic rays passing through their eyeballs. Since then dozens of astronauts have seen them (Clark, 2008).

[55] Known as À Mon Seul Désir (To My Sole Desire), scholars view the tapestry as possibly a celebration of chivalrous love or perhaps a renunciation of the pleasures of the senses (Boudet, 1999, pp. 62–63).


Credit: creative commons

Figure 4: La Vue (Sight), an allegory of the sense of vision.

From the six-tapestry collection, La Dame à la Licorne (The Lady and the Unicorn) in Musée National du Moyen Âge, Paris.

Sight has the greatest 'bandwidth' of all the senses, followed by hearing and touch. In other words, it has the capacity to receive and perceive the greatest quantity of information of any sense because it processes more types of input: for instance, shape, colour, brightness, depth of field and motion. Sight carries two orders of magnitude more information to the brain than the auditory sense which, in turn, carries two orders of magnitude more data than the tactual sense. Loss of this potent sense, even partially, can be enormously debilitating, especially for people who lose their sight later in life through disease, age or accident, as opposed to those blind at birth. Without training to develop compensatory strategies, blindness significantly limits the ability to perform everyday tasks (Way & Barner, 1997, pp. 82–83).

According to the World Health Organization (WHO), in October 2013, 285 million people were estimated to be visually impaired worldwide: 39 million were blind and 246 million had low vision (WHO, 2013b). In Australia, around 300,000 people have a substantial visual impairment not correctable by glasses, with around 20,000 totally blind (Australian Network on Disability, 2014).

For a person with normal sight, light travels through the cornea and the lens of the eye to the retina, located at the rear of the eyeball. There, approximately 130 million photoreceptor cells – rods and cones – process the visual input such that nerve cells, neurones, can transmit meaningful information along the roughly 1 million fibres of the optic nerve to the lateral geniculate nucleus, which further processes the data and relays it on to the visual cortex, the visual processing centre of the brain (Guenther, Lovell, & Suaning, 2012, p. 3; Mertz, 2012, pp. 10–11).

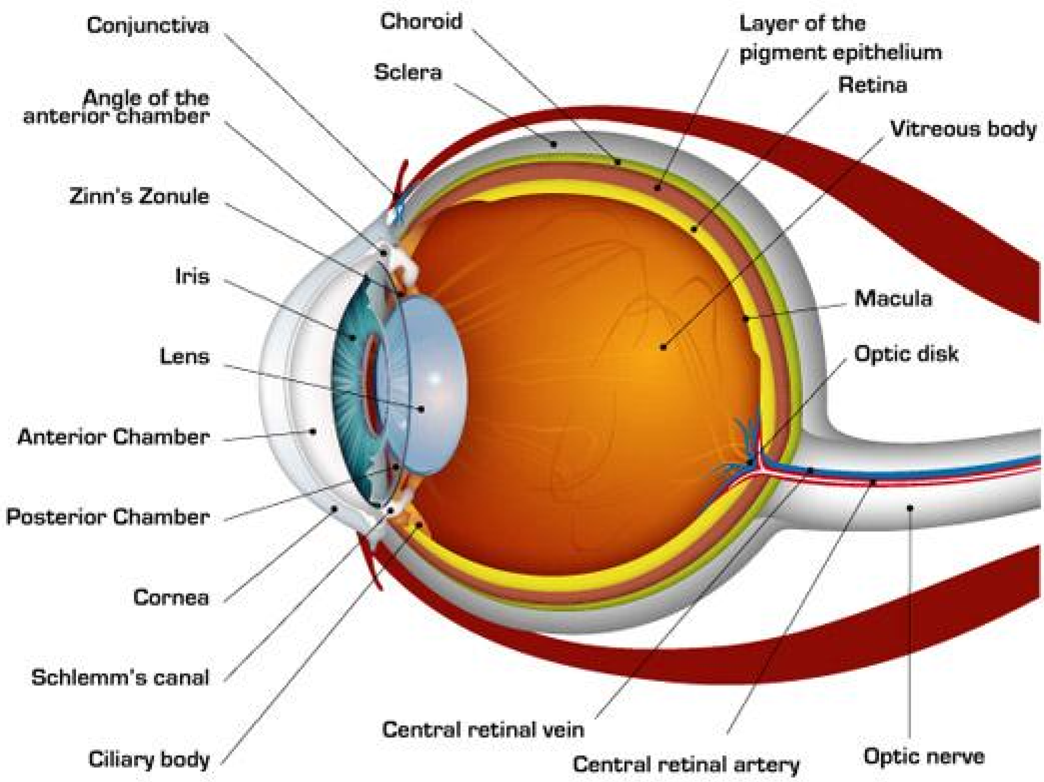

Figure 5: Anatomy of the eye

Source: http://www.rudyard.org/wp-content/uploads/2013/09/human-eye-diagram.jpg

Given the complexity of the visual pathway, it is unsurprising that deficits and/or errors can occur. The result can be impaired vision or complete blindness. Worldwide, the leading cause of visual disability is *cataract*, or clouding of the lens. It accounts for 51 per cent of cases but can be treated (WHO, 2013a).

The remaining causes of acquired blindness are *glaucoma*, caused by degeneration of the optic nerve, secondary to increased intra-ocular pressure; age-related *macular degeneration* (MD) which is loss of photoreceptors in the macula, the centre of the visual field; *diabetic retinopathy*, caused by diabetes-linked damage to retinal neurones which transmit signals to the brain; and *retinitis pigmentosa* (RP), or degeneration of photoreceptors in the retina. The most common non-preventable causes of blindness in developed nations such as Australia are MD and RP. There is currently no effective treatment for MD and RP, making them obvious targets for visual prosthetics (Dowling, 2005, pp. 1–2; Lorach et al., 2013, p. 422).

The development of the three basic approaches to treating MD and RP with a bionic eye will be discussed in the next section of this chapter. While none of these prostheses purport to restore normal vision, prototype and clinical trials indicate they have recovered stable functional vision that enables patients to perceive light, recognise shapes and objects and, for some, even read, although well below the legal blindness limit of 20/200. It is not surprising that ophthalmic surgeons claim this is a “major milestone” (Lorach et al., 2013, p. 430; Ong & da Cruz, 2011, p. 7).

The following sections outline milestones in efforts to treat blindness with visual prostheses, noting the three major sites of artificial stimulation -- brain, eye and optic nerve – the main components shared by bionic eye systems targeting them, and approaches to measuring the effectiveness of those systems.

Bionic building blocks

Over a decade ago, Australian computer scientist Jason Dowling[56] wrote a paper introducing the concept of artificial human vision. The fundamental technologies he identified have not changed since then (Dowling, 2005, pp. 2–3). As such, I will paraphrase his comments here. Because each of the systems described below aims to produce the experience or perception of ‘vision’ by stimulating a point along the visual pathway, they all have roughly the same basic technical requirements. His work is based on the Argus II Retinal Prosthesis System.[57]

Camera. The bionic eye systems discussed here all require a camera to capture and digitize image information. Many experimental models use a Charged Coupled Device, a miniaturised version of the light-sensitive digital imaging technology developed for

[56] Today, Dowling is a project leader at the CSIRO Australian e-Health Research Centre at the Royal Brisbane and Women's Hospital. He investigates the use of Magnetic Resonance Imaging in the treatment of prostate cancer.

[57] For details and a video presentation of the Argus II system see http://2-sight.eu/ee/product.

astronomy. As computing power advances, so too do experimental camera systems. With most systems, the camera is mounted on glasses.

Image processor. More data is collected from the camera than can be used by the prosthesis. An iPod-sized video processing unit (VPU) reduces the raw data into a format suitable for the specific system. The VPU is worn externally, generally attached to clothing or hung over the shoulder or around the neck.

Transmitter/receiver. Electronic connections send data from the camera to the VPU and from there to a receiver attached to the glasses or fixed externally near the site of the implant. The signal is then transmitted to the implant via radio frequency signals.

Implant. The implant receives the data and stimulates the site where it is located: the brain, the optic nerve or the eye. From there the signal is transmitted along the visual pathway.

Measuring success

THE Argus II retinal implant system is commercially available at a cost of US$144,000. But despite the hefty price tag people using the device do not have 20/20 eyesight. As Second Sight vice president Brian Mech[58] says, "We take patients who are blind and essentially bring them back up to low vision, so they have more independence". That means users are "better at orientation, mobility and some tasks of daily living". For example, users can avoid obstacles, know when people are approaching or moving away, find doors, and manage daily tasks like sorting laundry which are hard to do without sight (Mertz, 2012, p. 11).

The ultimate goal of bionic eye research is to replicate as closely as possible the sense of sight. While major advances are anticipated in the coming decade, this is a long-term goal. At present, teams are working to refine their current prosthetic systems. In the near-term they seek to provide "a useful degree of visual functionality" (Wagenaar, 2004, pp. 2–3). Physicist Daniel Wagenaar points to three objectives a functionally useful visual prosthesis might achieve: reading, mobility and facial recognition

Assessing the effectiveness of an individual prosthetic system against goals such as those articulated by Wagenaar is important. But according to pioneering researcher and

[58] Mech left Second Sight in 2015.

clinician William Dobelle, there is no objective method for comparing a bionic eye with a cane, guide dog or other aid. There are no models for testing colour vision and depth perception for people gaining low vision with a bionic eye. “There is no standard obstacle course on which such devices, or the performance of volunteers using them, can be rated” (Dobelle, 2000, p. 6).

This situation leaves researchers to devise their own measurement protocols. In published work, simple descriptions of what patients are able to see in laboratory trials are used. For example, patients could “see phosphenes corresponding to eye movements”, or could “see different shapes, line orientations and letters”. Others reports state that patients could “detect motion”, “see patterns and orientations”, or read letters at “a rate of 10 words per minute”.

A review of clinical reports, such as those mentioned in the following section, suggests that most of the tools used to measure the effectiveness of prototype bionic eye systems are based on elements of visual acuity tests, developed for clinical use by ophthalmologists. The clinical standard was set in 1984 by the International Council of Ophthalmology. In a nutshell, visual acuity is the degree of ability to see fine detail (Vision Australia, 2012).

Most systems use what is called the Snellen chart to test visual acuity. It displays rows of capital letters of different sizes, the biggest at the top and smallest at the bottom. Other character sets include so-called Tumbling Es in which the letter ‘E’ is positioned normally or upside down like an ‘M’. Landolt rings resemble the letter ‘C’ in various orientations, and Lea figures are shapes: squares, hearts and so forth.

Visual acuity tests are, technically, the measure of what the patient can see in-focus on the chart from a standard distance. In the US that is 20 feet and in Australia, 6 metres. The test result is given as a fraction indicating the distance in metres at which a specific row of letters can be read. The top number indicates the distance from the chart and the lower number the size of the letter.

In the US ‘normal’ vision is 20/20. That is, if a person has 20/20 vision, they can see clearly at 20 feet what is classed as “normal” to be seen at that distance. If they have 20/100 vision, they must be as close as 20 feet to read letters of a size that a person with normal vision can read at 100 feet. In Australia ‘normal’ vision is described as what a person sees at a distance of 6 metres (6/6 vision). For the purpose of entitlements in

Australia 'legal blindness' is visual acuity less than 6/60. A person classed as legally blind must be as close as 6 metres to see what a person with normal vision can see at 60 metres. Measures for 'reduced vision', 'low vision', and 'blindness' vary across jurisdictions (Vision Australia, 2012).

Technical measures of how a prosthesis or prosthesis component is functioning will depend upon what is measured and the units most appropriate, for instance electrical pulses would be measured in Hertz, or the charges needed to stimulate retinal cells would be measured in Amperes or Amps.[59]

In sum, researchers currently adapt various measures to assess the level of visual acuity achieved by their system for a patient and to test the technical performance of system components. To help put the measurement issue into context, consider that while its performance is continually being upgraded, when the Argus II was first commercialised in Europe the best visual acuity achieved was 20/1260, roughly 6 times lower than the blindness limit of 20/200 (Lorach et al., 2013, p. 424).

Measurement is critical at every step in the research and development process, regardless of where a visual prosthesis intervenes in the visual pathway. The following section describes the three sites researchers target in their quest for a bionic eye.

Three sites: The brain, the optic nerve and the eye

Earlier in this chapter I discussed how the sense of sight is produced at various stages along the visual pathway. In order to overcome pathway deficits which can impair vision or cause complete blindness, scientists are building devices that target specific locations. There are various reasons why sites are selected, for instance, ease of surgical access or the nature of a visual disorder.

This section discusses the three sites of intervention and the advantages and disadvantages posed at each, beginning with historical advances.

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59 The hertz is he number of cycles per second of a periodic phenomenon such as a musical tone. The ampere is a measure of the amount of electric charge passing a point in an electric circuit per unit time

Seeing stars in the 19th Century

For many years Otfrid Foerster was known primarily for his very famous patient. The German neurologist and neurosurgeon is legendary in medical history for his appointment in 1922 as Vladimir Ilyich Lenin's personal physician during the last two years of the Russian ruler's tumultuous life. But Foerster's reputation is now growing for a very different reason: he resurrected the 18th Century concept of stimulating the brain with electricity to produce vision (Sarikcioglu, 2007, p. 650).

While investigating disorders of mobility and sensation, as well as epilepsy, brain tumours and pain, Foerster discovered in 1929 that if he stimulated one of the occipital poles, located at the very tip of the occipital lobes of the brain, his blind subject would see phosphenes, the tiny spots of light noted earlier (Ong & da Cruz, 2012, p. 7; Suaning, Coroneo, Lovell, & Schindhelm, 1998, p. 195).

This finding linked the phenomenon of seeing spots of light more directly to stimulation of the visual system, compared with the more generalised Enlightenment observations. Subsequently, Berlin-based surgeon Fedor Krause and his colleague H. Schum reported in 1931 that they'd confirmed Foerster's finding by stimulating the left occipital pole of a patient blinded by a gunshot wound (Brindley & Lewin, 1968, p. 480).

These early German experiments triggered work on the notion that, with the right technology, the blind might see again. The concept of an electronic prosthetic device came to fruition in 1956. On August 28th Graham Edward Tassicker of Surry Hills, Victoria, Australia was awarded US patent 2760483 for his invention of a 'retinal stimulator'. Although it was not a clinical device, Tassicker demonstrated that a photosensitive selenium cell placed behind the retina of a blind patient produced phosphenes. "The effectiveness of my invention has been demonstrated in practice," Tassicker wrote in his claim (Tassicker, 1956, p. 2).[60]

The brain--cortex

While Tassicker pioneered the modern pathway to a retinal prosthesis, the most immediate follow-on from the German work focused on a different site along the visual

60 Tassicker further describes his invention in "Preliminary report on a retinal stimulator", *British Journal of Physiological Optics, 13*, 1956, pp. 102–105.

pathway: the cortex. This was conducted by British physiologist G.S. Brindley[61] and neurosurgeon W.S. Lewin at, respectively, Cambridge University and the United Cambridge Hospital. In their highly cited 1968 paper they credit "the old German observations" for encouraging them to investigate stimulation of the visual cortex, located in the occipital lobe (Brindley & Lewin, 1968, p. 479).

Very simply, the pair implanted an array of 80 electrodes in the brain of a 52-year-old blind woman. Using radio frequency transmission, they electrically stimulated the electrodes via a helmet with 80 receivers, each located directly above the electrodes. Their volunteer saw phosphenes which corresponded to her eye movements (Brindley & Lewin, 1968, pp. 479, 482–484). The experiment "set the standard" for all further such work and led to the concept of a bionic eye becoming "widely accepted in the scientific community (Suaning et al., 1998, p. 195).

As Brindley and Lewin were inspired by their German predecessors, biomedical engineer William Dobelle was inspired by Brindley and Lewin (Dobelle, 2000, p. 3). Along with his University of Utah colleague M.G. Mladejovsky, Dobelle published one of the pivotal papers in the evolution of the bionic eye. The 1974 paper was based on research conducted between 1970 and 1973. In it they report that they inserted implants into 37 sighted volunteers who were undergoing surgery on their occipital lobe to remove tumours and other lesions. After stimulating the implanted electrodes, Dobelle and Mladejovsky confirmed "most of the important observations" made by Brindley and Lewin (Dobelle & Mladejovsky 1974, pp. 553–555, 574).

Brindley and Dobelle, with their respective co-workers, were optimistic. Both teams were confident that if they improved their prototypes they could soon develop a prosthesis that would, to quote Brindley and Lewin, "permit blind patients not only to avoid obstacles when walking, but to read print or handwriting, perhaps at speeds comparable with those habitual among sighted people" (Brindley & Lewin, 1968, p. 492).

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[61] Giles Brindley is also noted for inventing an electronically controlled bassoon and giving one of the all-time show-stopping scientific lectures, appropriately in Las Vegas. During a talk on a novel chemical solution for reversing male erectile dysfunction at the American Urological Society's 1968 meeting, Brindley dropped his pants and revealed his own so-treated penis. See http://www.madscientistblog.ca/mad-scientist-12-giles-brindley/ for an entertaining discussion of Brindley's unusual presentation style.

Their optimism proved to be misplaced. Although Dobelle[62] went on to further refine the 'Dobelle Eye' and implant private patients at the Institut Dobelle AG, Zurich, Switzerland and at the Dobelle Institute in New York, technical difficulties limited progress. According to Daniel Wagenaar, a major problem for both groups was the large current required to stimulate the electrodes and the "limited resolution" of the results. "A long hiatus without new human experiments followed," he notes (Wagenaar, 2004, p 3).

By the early 1990s sufficient technical progress, primarily based on advances in computing technology, had been made to lure researchers back into the laboratory. Taking the lead was the Neuroprosthesis Program at the US National Institutes of Health (NIH). Teams there led by M.J. Bak and E.M. Schmidt were particularly productive, producing papers in 1990 and 1996 that built on Dobelle and Brindley's efforts and set the pace for the decade. The NIH program was discontinued by 2001, but the work continues at the Intracortical Visual Prosthesis team at the Illinois Institute of Technology, now headed by Phillip Troyk[63] (Dowling, 2005, p. 5; Bak et al., 1990; Schmidt et al., 1996).

Today, Troyk's is one of just a handful of research groups actively pursuing cortical implant work.[64] Others include the European Union's Cortical Implant for the Blind (CORTIVIS) program; Polystim Neurotechnologies Research Laboratory in Montreal; and the Norman Lab at the University of Utah, creators of the widely-cited Utah Electrode Array. This cortical implant is undergoing animal trials.

In Australia, a team at the Prince of Wales (POW) Hospital in Sydney and the University of New South Wales – what I call the 'Sydney group' -- began experimentation with both cortical and eye implants in the late 1990s, but disbanded with key players moving to other teams. However, the Monash Vision Group (MVG), a

[62] Dobelle's work raised ethical concerns, especially in later years. The reason is that he charged his patients to participate in his experiments. There are allegations Dobelle also abandoned implanted patients. At his death in 2004 it was decided not to sell the intellectual property but to donate it to a publicly funded research team at Stony Brook University in New York (Mertz, 2012, p. 16; SUNY, 2006).

[63] Troyk leads a team that is tracking down and interviewing people who participated in early cortical implant experiments, including those of William Dobelle. "Those were very controversial experiments," claims Troyk. The study seeks to understand the experience of the volunteers to enable researchers to more ethically and effectively involve volunteers in future studies (Mertz, 2012, p. 16).

[64] See Appendix 5 for a listing of the teams involved in the development of the bionic eye.

consortium comprising the Monash University and Alfred Hospital in Melbourne, anticipates testing a cortical prototype on a human volunteer in 2018.

The fundamental approach taken by such groups is to target the visual system at the deepest level of the visual pathway, the cortex. The main advantage of this approach is that it is suitable for people who have non-functioning retinae or optic nerves, the majority of all visually impaired and blind people. As I note later in this section, most bionic eye groups are working on implants on or adjacent to the retina which are effective for MD and RP, but do not resolve deficits further along the visual pathway.

The main disadvantages of targeting the cortex are the complexity and risks of implantation surgery, haemorrhage and infection, along with incomplete knowledge of how to replicate the functions of the retina and optic nerve when compressing incoming information and reassembling it into something the brain is able to recognise as visual stimulation (Guenther et al., 2012, p. 5; Lorach et al., 2013, p. 429; Mertz, 2012, p. 14; Ong & da Cruz, 2012, p. 14).

To date, technological advances continue in directions such as reduction of power requirements, optical stimulation, and image processing (Brunton, Rajan, & Lowery, 2013; Dong, Sun, & Degenaar, 2012; Kaskhedikar, Hu, Dagnelie, & Troyk, 2013). But while prototypes have been tested, as I write, no team has yet gone to clinical trials with a cortical bionic eye.

The optic nerve

The optic nerve is the mid-level of the human visual system, sitting between the cortex and the eye itself. A collection of an estimated one million individual fibres, its job is to ferry information processed by the retina to the lateral geniculate body (LGB). Located inside the thalamus, the LGB further processes data and sends it on to the visual cortex which converts it into ‘sight’. Because, like the cortex, the optic nerve can be reached surgically and, in theory, could enable treatment of a greater proportion of patients affected by visual disease than retinal interventions, it is an alternative site for stimulation by a visual prosthesis (Dowling, 2005, p. 13; Guenther et al., 2012, pp. 3–4; Ong & da Cruz, 2012, pp. 12–13).

There are, however, few groups working on optic nerve prosthesis. Belgian researcher Claude Veraart of the Neuronal Rehabilitation Engineering Laboratory (NREL) at the

Universite' Catholique de Louvain, is widely regarded as the pioneer of this approach. Between 1996 and 2000 he headed the European Union funded Microsystems-Based Visual Prosthesis (MiVip) consortium. The group conducted studies with a self-sizing spiral cuff implant, designed by Veraart, which wrapped around the optic nerve (Dowling, 2005, p. 13; Guenther et al., 2012, p. 14).

In 1998 MiVip reported implanting a blind 59-year-old volunteer with a prototype of the system. After training with the device, she could perceive different shapes, line orientations and even letters after slowly scanning the pattern with a head-mounted camera for up to 3 minutes per pattern (Veraart et al., 1998). Further refinements included a camera mounted on glasses which sent signals to the implant which, in turn, passes information to the brain.

Having demonstrated the viability of the optical nerve cuff implant, the MiVip project was succeeded by a second EU-supported project: the Optimization of the Visual Implantable Prosthesis project, or OPTIVIP. Veraart again headed the project, which ran from 2001 to 2005.[65] The advances made by MiVip and OPTIVIP are being built upon, primarily by the NREL in Belgium and multidisciplinary teams in China.[66]

The Chinese Project for Sight (C-Sight) is the first bionic eye program funded by the Chinese Ministry of Science and Technology. Established in 2004, the group is modifying the MiVip-OPTIVIP design. Instead of a camera mounted on glasses, their prototype has a tiny camera implanted in the lens of one of the blind volunteer's eyes. The camera and the optic nerve cuff are connected to a visual processing unit outside the eye, and a commercial radio frequency chip from Texas Instruments transmits data. Project scientists continue refinements to the technology and the underlying biophysiology (Guenther et al., 2012, p. 14; Guo, 2012; Ren, Chai, Wu, & Zhou, 2007, pp. 187–207; Wu, Zhang, Huang, Li, & Ren, 2010).

In summary, work continues on systems for stimulating the optic nerve. I could not, however, find reports of proposed or completed clinical trials in the literature at the time of writing. Similarly, no Australian groups appear to be exploring this approach. The bulk of all bionic eye research is based on implants on or in the eye, as detailed below.

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65 For detailed results of the MiVip and OPTIVIP Projects see http://www.gren.ucl.ac.be/intro.html.

66 Small groups in Slovenia and Japan are also pursuing optic nerve prostheses.

The eye

2013 was a big year for Second Sight Medical Products, Inc. The California based firm was granted US Food and Drug Administration approval to market its Argus II Retinal Prosthesis System in the US market and, as covered above, Time magazine nominated the Argus II as one of its “Best Innovations of the Year”. This good fortune was the legacy of decades of scientific groundwork targeting the first level of the visual pathway, the eyeball itself -- the site of the most advanced bionic eye systems developed to date.

It was an intellectual journey that harked back to Tassicker’s 1956 patent. Just as Tassicker demonstrated that stimulating cells behind the retina produces phosphenes, a group in the US had a similar idea years later. The team included University of North Carolina doctoral student and physician Mark Humayun, Eugene de Juan with Duke University at Durham, North Carolina, and de Juan’s neighbour, electrical engineer Howard Phillips. The three began collaborating at Duke and in 1992 were granted a US patent on a bionic eye aimed at treating people with retinitis pigmentosa (de Juan, Humayun, & Phillips, 1992; Dowling, 2005, p. 11).

Meanwhile, Johns Hopkins University student Robert Greenberg was introduced to de Juan by his supervisor, Richard Johns, and began working with the team in the early 1990s. Not long after receiving his medical and doctorate degrees in 1998, Greenberg co-founded Second Sight with the support of entrepreneur and philanthropist Alfred Mann.[67] He continued collaborating with Humayun and de Juan, both by then based at the Doheny Retina Institute at the University of Southern California. Advances soon followed: international clinical trials, European approval (CE Mark) for the system in May 2011 and on 14 February 2013 US Food and Drug Administration (FDA) approval to market the Argus II Retinal Prosthesis System (Mertz, 2012, pp. 11–12; Ong & da Cruz, 2011, pp. 8–9; Second Sight, 2012).

Second Sight, however, was not the first group to enter the scientific race to develop a retinal prosthesis. In 1990 the US the Retinal Implant Research Group at the Massachusetts Institute of Technology (MIT) and the Massachusetts Eye and Ear

[67] Over the years Mann's companies have dominated the markets for pacemakers (Pacesetter), insulin pumps (Minimed) and cochlear implants (Advanced Bionics). http://www.forbes.com/profile/alfred-mann/

Infirmary began work on a prosthesis for people with RP and MD. The leaders were MIT ophthalmologist and neurologist Joseph Rizzo and electrical engineer John Wyatt.

The pair built their collaboration into a multi-centre consortium, including the Boston Retinal Implant Project with partners in New York State; and Bionic Eye Technologies Inc, headquartered in New York State. While still far from Food and Drug Administration (FDA) approval or a CE Mark, Bionic Eye Technologies Inc anticipates taking their fifth-generation implant to clinical trials soon (Boston Retinal Implant Project, 2014; Dowling, 2005, p. 12; Mertz, 2012, p. 12).

While the Second Sight and MIT groups were beginning their respective collaborations, European scientists were also investigating the possibilities of a retinal bionic eye. At the forefront was ophthalmologist Eberhart Zrenner with the University Eye Hospital in Tübingen, Germany. In the mid-1990s he formed a multi-institution group of engineers, biologists and surgeons – the 'Subret Consotrium' – which acquired funding in 1995 to develop a retinal bionic eye. With a prototype in hand the group began animal trials in 2000 (Dowling, 2005, pp. 9–10; Park, 2004, pp. 150–151; Tübingen Eye Hospital, 2014).

Despite their success with early prototype tests with patients, Zrenner and colleagues were unable to attract a major corporate partner. Nevertheless, as they say on their website, "with the help of local entrepreneurs" they started Retina Implant AG (RI) and began clinical trials.[68] Based on the consortium's first multi-centre clinical trial results published in 2010 (Zrenner et al., 2010), their prosthesis, Alpha IMS, received Europe's CE Mark on 6 November 2013 and went to market.

According to results of the company's second clinical trial, patients with the Alpha IMS implant can recognise faces and read signs on doors (Stingl et al., 2013). But like Second Sight, the consortium continues technical innovation and clinical study on their approved system, now involving groups in Oxford, London, Hong Kong, Budapest, Kiel, Dresden and Singapore (Ong & da Cruz, 2011, pp. 10–11; Tübingen Eye Hospital,

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68 For details see "From a 'crazy academic idea' to an attractive product". http://www.eye-tuebingen.de/zrennerlab/technology-development/

2014). The firm's second-generation model, Alpha AMS, was approved for sale in 2016 and is now on sale.[69]

In Australia, the Sydney group entered the prosthesis field in the late 1990s, publishing their first paper in 1998. As noted above, the small multi-institutional team also worked on cortical implants.[70,71] The group's most advanced prototype device, however,[72] was based on bionic ear technology commercialised by Cochlear limited in Sydney, and it was designed to sit outside the retina on the sclera. They selected an external site as it would be safer and cheaper than a retinal implant (Dayton, 2009).

After feasibility, animal and sensitivity trials with 10 volunteers, the group was ready to implant two prototypes into patients in 2008 with the help of volunteer surgeons (Chowdhury, Morley, & Coroneo, 2004). Due to funding shortfalls, however, the trials did not proceed and the group eventually disbanded (Dayton, 2008a, 2008b).[73]

Today, research and development on visual prosthesis on or near the retina is booming. Collaborations are shifting. Approaches are diverse. Australia's current contenders are the multi-centre consortium Bionic Vision Australia (BVA), launched in 2010 and headquartered in Melbourne. In their 2012 review paper, BVA biomedical engineer Thomas Guenther and his University of New South Wales (UNSW) colleagues Nigel Lovell and Gregg Suaning describe 16 different international groups engaged in retinal prosthesis research (Guenther et al., 2012). Similarly, Paris-based biomedical engineer Henri Lorach, with Institut de la Vision, and his co-authors discuss the work of 10 active groups worldwide (Lorach et al., 2013, p. 423).

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[69] See https://www.medgadget.com/2016/04/retina-implants-higher-resolution-alpha-ams-visual-implant-cleared-in-eu.html

[70] Before splitting into two groups it included Minas Coroneo and fellow POW ophthalmic surgeon Vivek Chowdhury, University of New South Wales (UNSW) biomedical engineers Gregg Suaning and Nigel Lovell, and UNSW physiologist John Morley, along with technical assistance from Cochlear's Jim Patrick

[71] Today, Coroneo is at POW Hospital and UNSW. Chowdhury is in private practice. Suaning and Lovell are with UNSW and participate in the BVA consortium. Morley contributes to the BVA but is at the University of Western Sydney, while Patrick continues with Cochlear Ltd and is on the advisory board of the Monash Vision Group.

[72] Patent applications were filed in the US and Europe in 2004. United States Patent 7,877,148 was granted January 25, 2011.

[73] The context in which the Sydney team failed to secure continued funding and disbanded will be discussed later in this chapter.

Diverse as each collaboration is, it is possible to identify three main strategies for eye-based prosthetics: stimulating the back and inner surface of the eye (epiretinal); between the retina and the choroid (subretinal), or the outer portion of the eye, between the choroid and the sclera (suprachoroidal). Each site has advantages and disadvantages. Important variables include ease of surgical access, the power needed to stimulate the implant, the amount of intact visual processing at each site, dissipation of heat, and degree of contact between the implant and the target cells. Not surprisingly, each group argues for their choice of site and technology.[74]

Technological 'bottlenecks' remain, among them further miniaturisation of implant components and long-term comfort and safety. As well, in order to increase the amount of data delivered from the eye to the visual pathway, it is necessary to develop stimulators capable of simultaneously triggering hundreds of retinal cells, along with enhanced data transmission systems and real-time VPUs able to process and transmit the increased data. But to borrow from Guenther and his colleagues, if a gauge of future success for a clinically useful bionic eye is linked to the research activity within a field, then there is "great promise" for a retinal prosthesis (Guenther et al., 2012; Lorach et al., 2013, p. 430).

Summary: The brain, the optic nerve and the eye, and beyond

For Australians, the concept of a commercially available bionic ear is widely understood. The slow rise and ultimate global success of Graeme Clark and the company he founded, Cochlear Ltd, is often cited as a classic example of successful Australian innovation. Setting aside the issue of whether or not Australian innovation, generally, is as successful as Clark has been, there is no doubt he and his team have improved the lives of people worldwide.

There is also little doubt that the success of Cochlear's bionic ear leant weight to the modern notion of a bionic eye. A review of the scientific progress of the field shows the concept of a bionic eye is realistic, albeit one that has offered and will continue to offer complex challenges. By pulling together multi-disciplinary teams, groups in Australia and around the world have made progress targeting different sites along the

[74] For details on the strengths and weaknesses of each approach see Lorach et al., 2013; Dowling 2005; Ong & da Cruz, 2011; Guenther et al., 2012; and Shepherd et al., 2013. Web sites for each group also highlight the site and technology of choice.

visual pathway, with eyeball-based prostheses already having an early clinical impact (Ong & da Cruz, 2012, p. 6).

Beyond the three sites discussed here, more futuristic techniques for managing blindness are entering the innovation pipeline. A team at Israel's Bar-Illan University, for instance, has developed a 'bionic contact lens' that bypasses the retina while stimulating the visual pathway (Even, 2013). The multi-centre IMT002 Study Group in the US has conducted trials of a miniature 'implantable telescope' for people with MD (Hudson et al., 2006; Hudson et al., 2008).

Further, scientists at the University of California, Berkeley, have developed an injectable compound called AAQ that, in mice, makes cells of the inner retina light sensitive when nerve cells of the outer retina have been lost or damaged (Ross, 2014). And a British team has trialled gene therapy for people with a rare degenerative disorder called choroideremia which they suggest may also work with RP and MD (MacLaren et al., 2014).

Advances in stem cell science offer promise for a biological approach for managing blindness. Stem cells are the building blocks of the body's tissues. 'Embryonic' stem cells can develop into all types of tissue, while 'adult' stem cells are tissue-specific. Japanese researchers developed a procedure for turning adult stem cells into the more versatile embryonic stem cells. British surgeons have implanted the resulting 'induced pluripotent' stem cells (iPSC) into a patient in order to reduce or reverse MD (Walsh, 2015). And in Japan a multi-institutional group announced in early 2017 that they will transplant iPSCs into five patients, also to treat MD.[75]

Gene therapy is another emerging therapeutic approach for blindness. Using a gene-editing technique called CRISPR, US researchers have repaired a mutation responsible for RP in a single patient.[76] In the UK, the MacLaren group introduced stretches of genetic material that supplemented the activity of a defective gene into six patients with choroideremia. Two of the six had improved vision after four years (Edwards et al., 2016, pp. 1996–1998).

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[75] See http://www.riken.jp/en/pr/topics/2017/20170207_1/

[76] See http://www.eurekalert.org/pub_releases/2016-01/cumc-cut012616.php

Perhaps the most surprising approach for treating blindness may come from a study of zebrafish. Researchers in the US and UK have discovered that, along with some amphibians, the fish can turn on an enzyme in their eyes that supercharges their ability to see infrared light, sharpening vision in murky water (Enright et al., 2015). Team member Joseph Corbo of Washington University School of Medicine in St. Louis says humans have a copy of the gene which controls the enzyme, though not in the eye. He suggests it could be combined with "optogenetic devices" to treat neurological and blinding diseases (Dunham, 2015).

But, realistically, the prospects for such intriguing approaches are years away. Meanwhile, as discussed above, retinal devices are commercially available overseas, albeit at high prices. Regardless of which technology, or technologies, proves successful, or most successful, in the market place, an important question for this thesis remains.

Given that Australian scientists joined the international race to develop a bionic eye in the late 1990s, and, as I discuss below, there was a financial and political impetus behind the nation's work, why did the country fall behind its international competitors? To begin to answer that question it is necessary to understand the history of Australia's quest for the bionic eye.

Australia's quest for the bionic eye

In April 2008, newly elected Prime Minister Kevin Rudd held an ideas summit. He invited 1000 prominent Australians of diverse fields to attend the Australia 2020 Summit. Others joined in through local summits held across the country. The task was to "shape a vision for the nation's future" and to discuss ways to meet "future challenges", wrote Rudd in his response to the Summit (Government of Australia, 2009b).

The weekend event -- co-chaired by Rudd and Melbourne University Vice-Chancellor Glyn Davis -- generated hundreds of ideas, nine of which were picked up as new initiatives by the Rudd Government. On the list was "research in bionic vision science and technology to support the development of the bionic eye in Australia".[77] It was, said

[77] Others were a deployable civilian emergency response capacity, an indigenous cultural education & knowledge centre, mature age mentoring schemes, a Prime Minister's Asia-Australia cultural

Rudd, "a huge public good that we should be engaged in" (Davis, 2008; Dayton, 2008c).

At the time of the summit, I was the Science Writer at *The Australian* newspaper. The Monday following the event I rang around to find out what, if anything, was happening with bionic eye research in Australia. In less than two hours I learned of the work of the Sydney group, as well as the international competition to get a product to market.[78]

I reported Minas Coroneo's claim that the group had developed a basic prototype for less than $100,000 and that they were going to trial with a single volunteer, as soon as key components for the system arrived from Cochlear Ltd. The group was excited about the summit announcement and the possibility of obtaining $100,000 to conduct a Phase One clinical trial (Dayton, 2008a).

At the time, I was unable to locate any other similarly advanced projects in Australia. Recent literature reviews support my observation. One Google Scholar search identified no publications or patents between 1990 and 2000 by any Australian researchers except those involved with the Sydney group.

A second search from 2001 to 2008, the year of the 2020 Summit, found 1330 publications or patents, of which only six had Australian co-authors who were not in affiliated at any time with the Sydney team and over 300 from those who were.[79] A more recent and detailed search using the Embase, Scopus, PubMed, Science Direct and Web of Science databases produced similar findings for the search terms 'visual prosthesis' or 'bionic eye'.

Despite Rudd's post-summit enthusiasm for a bionic eye project, it was not until April 2009 that then Science Minister Senator Kim Carr and Health Minister Nicola Roxon jointly announced funding of $50.7 million over four years for "the development of the bionic eye in Australia". The funding would be administered by the Australian Research

scholarship, a dedicated ABC children's channel, a business-school roundtable, a carbon challenge initiative and a vocational education broadband network.

[78] Given how easy it was to identify the POW group I was surprised that the co-chair of the 2020 Summit's health section, Queensland Institute of Medical Research director Michael Good, said members of his group knew nothing of the Sydney work (Dayton, 2008).

[79] On 19 February 2014 I ran two Google Scholar searches for the term "visual prosthesis", one between 1990 and 2000 and the other, 2001–2008.

Council (ARC). "The funding will help Australia stay at the forefront of research and commercialisation," the announcement stated (Carr & Roxon, 2009).

By that time the Sydney group had split in two, as Suaning joined forces with fellow UNSW biomedical engineer Nigel Lovell. Minas Coroneo and Vivek Chowdhury formed a group based at the Prince of Wales Hospital in Sydney (POW group). The result was two competing bionic eye groups, one in engineering and the other in medicine, each of which developed separate collaborations.

Ultimately, seven applications were submitted by individual consortia to the ARC,[80,81] including two based in Melbourne -- one of which included Suaning and Lovell -- an unsuccessful one from a consortium involving Coroneo and Chowdhury, and another headed by the University of Queensland which included Second Sight and its collaborators at the University of Southern California's Doheny Retina Institute.[82]

Three proposals were shortlisted and two were approved for funding.[83] The University of Melbourne-led consortium (later named BVA) received $42 million over four years; and the Monash University-led Monash Vision Group (MVG) was awarded $8 million, also for the period 2010-2013. The funding was extended in July 2013, enabling both groups to continue for another year. BVA received an additional $8 million and MVG, $1.9 million (Carr, 2009, 2013).

Without further analysis, it would seem surprising that more advanced groups were overlooked in favour of the Melbourne-led consortia. The POW group had publications, a patent and a prototype ready for trial. Second Site, which had applied for funding with

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[80] The Selection Advisory Committee comprised: Dr Mike Hirshorn, Director, Four Hats Capital Pty Ltd (Chair); Professor Philip Luthert, Institute of Ophthalmology, Director & Head of Division of Pathology, University College London; Professor Mike Calford, Deputy Vice Chancellor (Research), The University of Newcastle; and Mr David Money, a retired biomedical engineer (Correspondence from Dr Liz Jazwinska ARC to Professor Minas Coroneo).

[81] The ARC document "Call for Proposals for the Research in Bionic Vision Science & Technology Initiative" can be viewed at http://www.arc.gov.au/sites/default/files/filedepot/Public/NCGP/SRIs/PDF/SRI_BE_call_proposals.pdf.

[82] Coroneo & Chowdhury, Queensland, and Second Site considered forming a consortium, but they went separate ways due to commercial conflict between the US and Australian commercial participants (e-mail correspondence between the proponents; participant interviews).

[83] The ARC declined to identify unsuccessful bidders, citing confidentiality.

Queensland, was the acknowledged world leader in bionic eye research and was a few years from gaining marketing approval for its Argus II Retinal Prosthesis.

At the time of the 2013 top-up, neither BVA nor MVG had proceeded to clinical trials. Meanwhile, Second Sight had begun sales in Europe and the UK and was about to receive FDA approval for commercialisation in the US. Australia had spent nearly $60 million, as Rudd said, "to develop the bionic eye in Australia", but was beaten to commercialisation by Second Site, as well as Germany's Retina Implant AG.

Current projects by BVA and MVG may become commercial successes in time. Similarly, there is no guarantee that had the original Sydney group run a clinical trial, an Australian bionic eye would be on the market today. But it is worth noting that after the Queensland-Second Sight bid was unsuccessful, the company's Chief Executive Officer Robert Greenberg wrote to Ministers Carr and Roxon, warning that Australia's go-it-alone effort would be "insufficient to produce a commercial bionic eye" (Dayton, 2011).

Summary

Sight is humanity's most powerful sense. It enables critical data about the environment to be collected and processed in useful and pleasurable ways. People without the sense of sight must enhance other senses and develop other strategies for managing in a 'sighted' world. The notion of assisting with such adaptation is the driving force behind the centuries-long evolution of vision-enhancing procedures and, eventually, technology.

Key advances emerged from the intellectual ferment of Enlightenment in the late 17th and 18th Centuries. The era saw new discoveries about the nature of world, discoveries based on observation rather than logic or belief alone. The discoveries about electricity and associated phenomena such as 'seeing stars', or phosphenes, gave the dream of 'curing' blindness a solid foundation. That goal came into sharper focus with developments in medical and biomedical research in the 20th Century. The first practical device, a true but rudimentary bionic eye, entered the market in 2011.

While significant international work had begun in 1990s, the idea that Australia could be amongst the first – if not the first -- to develop and commercialise a bionic eye emerged from the Australia 2020 Summit, convened by the Rudd Government in 2008. The resulting $60 million national initiative supported the creation of two major research and commercialisation consortia, BVA and MVG. But this support was not enough to see either group develop, manufacture and commercialise a functional bionic eye ahead of international competitors.

As noted in Chapter I, Australia's nationally devised and funded project to build a bionic eye is the case study for my examination of the nation's innovation system. In later chapters I will present information from participant interviews and use the National Innovation Systems framework (discussed in Chapter 1) to critically assess Australia's innovation system. My goal is to identify ways to enhance the effectiveness of the nation's innovation effort as it moves into the age of complex, multi-disciplinary, multi-national science.

Chapter 4: Methodology

Introduction

In earlier chapters I discussed the goals of this thesis. They are, firstly, to identify the structural and interpersonal strengths and weaknesses of the Australian innovation system, and secondly, to use that analysis is to provide recommendations for boosting the nation's innovation output.

The historical and quantitatively oriented material presented in Chapter 2, *Innovation in Australia,* provides important data. However, a major portion of my investigation is a qualitative study using the bionic eye initiative as a case study. It provides insight into the drivers and dynamics of the nation's innovation system from the stakeholders' perspective.

This chapter describes the qualitative methods used in my data collection and subsequent analysis of participant interviews and communications. In order to provide clarity and demonstrate methodological rigour, I have organised this chapter around the domains of the Consolidated Criteria for Reporting Qualitative Research (COREQ) checklist (Tong, Sainsbury, & Craig, 2007)[84]. The three domains are:

1. Researcher reflexivity. Researchers must attempt to understand and make clear preconceived ideas and their relationship with their participants.
2. Study design. Researchers must make clear their theoretical framework, along with details of participant selection, and data collection.
3. Analysis. Researchers must provide details of their data analysis and the presentation of their findings.

Domain 1: Researcher reflexivity

Personal characteristics

As a science journalist I had observed many examples of potentially viable applied research fail to reach commercialisation in Australia. Before beginning this thesis, I

[84] https://www.elsevier.com/__data/promis_misc/ISSM_COREQ_Checklist.pdf

held assumptions about the structural and interpersonal reasons behind the observation. As British health care experts Sue Ziebland and Ann McPherson (2006) state, it is important to recognise and utilise preconceived ideas, but not to be constrained by them. Throughout this thesis, I attempt to follow their advice.

I do so by following a theoretical framework, discussed below, which helps to reduce bias, and by disclosing my background to readers.

Relationship with participants

I also discussed my past experience with participants, many of whom I had met and/or interviewed over the course of my journalism career. It was important to inform them that as a doctoral student I sought to present their ideas and experiences as objectively as possible. I agreed to check quotes and data obtained from their interviews with them for accuracy.

Domain 2: Study design

Theoretical framework

Taken as a whole, my thesis can be understood as what Charles Edquist calls a "diagnostic analysis" of Australia's innovation system (Edquist, 2001, pg 1725). The background to my analysis includes theoretical insights from the National Innovations Systems (NIS) model (see Chapter 1) and the material presented in Chapter 2. Both of these are central to my understanding of the history and structure – the context -- of the nation's approach to science and innovation. That earlier material complements findings from my qualitative analysis of the bionic eye initiative case study in Chapters 5-9.

Data sources

This thesis draws on more empirical material than just the qualitative interviews discussed below. I have identified and reviewed key policy and review documents from 2001 to mid-2017 (See Appendix 2). My goal was two-fold. First, to identify recurring themes and changes which reflect successive federal governments' understanding of the role of science and innovation to the nation's economic and social wellbeing. And second, to pinpoint notable changes in funding, programs, priorities and projects.

I also reviewed books about and peer-reviewed articles assessing Australia's innovation system. But much relevant commentary on current events affecting the nature and operation of the system comes from 'grey literature'. This includes articles by journalists, researchers and other experts published in daily newspapers and/or electronic media. It also includes pieces written by academic experts for *The Conversation*, an online university-sponsored publication which serves a diverse audience, from politicians and academics to the general public.

Further, I cite government submissions, background information and other material, produced by relevant organisations such as Bionic Vision Australia, the Australian Research Council, and company and association websites. All this diverse information adds depth, detail and lived experience to the more rigorous data published in peer-reviewed journal articles and independent government-initiated reviews.

Participant selection and recruitment

Before approaching any potential interviewees, I sought ethics approval for my project, then titled "Australia's Quest for the Bionic Eye and the Politics of Innovation" (REF: 5201300423). Approval was granted, effective 22 July 2013, by the Macquarie University Human Research Ethics Committee (see Appendix 6).

I recruited representatives from each of the relevant stakeholder groups: politicians and their advisors, researchers, consultants, and representatives from funding bodies, academe, and industry. The process was facilitated by my previous experience as a journalist. Because I had covered the story of the bionic eye initiative extensively as the Science Writer for *The Australian* newspaper, I had preliminary knowledge of the leading participants. I contacted each potential participant by phone. After gaining in-principle permission to be interviewed, I sent them by e-mail the participant information sheet and the consent form for their further information and signature (see Appendix 7).

In addition to the above steps, I used snowball sampling. By asking each previously-identified participant to identify others, I was able to ensure that I approached key players in the initiative, including individuals I had not encountered when reporting on it as a science writer. This aspect of the recruitment process helped to ensure that research yielded an accurate account of key events (Bernard, 2006, p. 192; Minichiello et al., 1995, p. 161).

In total, I approached 34 potential participants. Five declined to be interviewed, either verbally or in writing. Two refused to be interviewed in person, but agreed to respond in writing to questions which I provided to them. In sum, I interviewed 29 participants who were directly or indirectly involved in the bionic eye initiative. While my final tally does not reflect the hundreds of people involved over time in the initiative, it includes representatives from each of the relevant participant categories: politicians and their advisors, researchers, consultants, and representatives from funding bodies, academe, and industry. All the people included in my sample were involved with the project at critical stages of the bionic eye initiative.

Data Collection

Once people agreed to be interviewed, I followed the steps outlined by Greg Guest and colleagues in a 2006 publication: 1) record interviews 2) transcribe verbatim responses 3) review transcripts against the recordings and correct any errors made during transcription. In terms of the interviews themselves, I treated the process as a guided, or active, conversation, encouraging participants to discuss predetermined areas. In other words, I used semi-structured interviews employing a guide covering set questions and themes (Minichiello et al., 1995, p. 65; Guest, Bunce, & Johnson, 2006, pp. 64, 77).

Specifically, I asked participants to state their area of expertise, current professional position, and their position and role during their participation in the bionic eye initiative. I then prompted them to describe their experience with the initiative, asking follow-up questions for clarification. Next, I asked them to discuss what they saw as the strengths and weakness of Australia's innovation system, based on their experience with the initiative. Finally, I asked participants if they had recommendations for enhancing future national initiatives like that of the bionic eye, and, if so, what they are.

Building on information obtained from early participants, I refined the way I asked questions in subsequent interviews to elicit information about the general areas noted above (Bernard, 2006, p. 210; Britten, 2006, pp. 13, 16–17).

This approach enabled each participant – all busy professionals with limited time -- to tell their story efficiently, but in a seemingly unhurried manner (Bernard, 2006, p. 212).

A small number of participants were initially hostile,[85] but all settled into a conversational mode once they recognised I was neither taking sides, nor pursuing a particular agenda.

Interviews ranged from roughly 45 minutes to over an hour in duration. One participant requested that we continue the conversation at a second time due to an upcoming meeting. Another rang back to raise additional points. All but two of the interviews were conducted by phone because of time and location constraints.

Of the 29 participants in my research, 18 agreed to be quoted by name. But after discussion with my supervisors, I chose to cite data they provided anonymously. The central individuals in the bionic eye initiative know one another. It was, therefore, likely that that they would be able to identify participants who wished to remain anonymous by a process of elimination, starting with quotes from identified sources. However, when I discuss participants noted or quoted in public documents, I name them.

Domain 3: Analysis and findings

Data Analysis

After conducting my first few interviews and checking and familiarising myself with the transcripts, I began the analytical process. This was an iterative process in that I revised elements of my analysis as I gained more information.

In order to gain as much information as possible from the interviews, I used inductive thematic analysis as my analytical method for discovering themes existing in the data (Fereday & Muir-Cochrane, 2006, pp82-83). Fundamentally, it is a bottom up approach that starts with the data. This helps to ensure my coding decisions and analytical observations were based on what participants said, rather than on predetermined ideas. During this process, my coding was informed by my prior research on the NIS, such as the position within the innovation system held by each participant.

Using NVivo software as a tool for organising my analysis, I began coding the interviews. That is, I identified relevant sections from the transcripts and collected them under various headings, such as “risk aversion”, “geography”, “metrics”, “political

[85] I presume this attitude developed because I had reported on the work of the major research groups involved in the Bionic Eye initiative in my role as a journalist.

cycle", and "rivalry". After conducting about half of my 29 interviews, I began grouping these initial headings into larger themes, or nodes. For instance, "risk aversion" became a sub-node of "cultural barriers". I continuously refined my nodes and sub-nodes as I conducted further interviews.

During this process, I also looked for contradictions in participants' understanding of events (Pope, Ziebland, & Mays, 2006, p. 76; Ziebland & McPherson, 2006, p. 405). I had no trouble finding examples. The participants in my case study had strong opinions that influenced their interpretations of key events, not to mention one another. While they disagreed on many points, their areas of contention, like their areas of agreement, provided rich, descriptive detail, helping to shape my emerging analytical themes.

Finally, I identified over-arching themes which allowed me to obtain in-depth understanding of the participants' experience of the Bionic Eye initiative, along with their insights into the strengths, weaknesses, and dynamics of Australia's innovation system.

Reporting

The themes I identified are **Revised History**, **Academic Culture**, **Culture Clash**, and **Structural Barriers**. I present my thematic findings in Chapters 6-9. In Chapter 5, *The Revised History*, I present a revised history, based on behind-the-scenes, often confidential, detail about what happened during the Bionic Eye initiative, and compare this with the official history presented in the Chapter 3.

I explore dynamics within the *Academic Culture* in Chapter 6. There, I tease out the pressures participants within the university system face as they work to build their professional profile and advance their science and their career. These pressures affect they ways they collaborate, or do not collaborate, with one another.

Similarly, in Chapter 7, *Culture Clash: The Influence of Industry & Political Cultures*, I discuss the barriers, identified by my participants, to innovation created when people working in the industry or political sectors interact with the academic sector. Each group has its own "culture". These differing sets of values and expectations frequently clash with unproductive consequences.

Structural barriers to innovation emerge from the nature of the system itself, its history, components and the connections between them. Many barriers are closely intertwined.

In Chapter 8, *Structural Barriers to Innovation: Politics & Funding*, I explore how participants understand and experience the impact of the nation's 3-year political cycle on the innovation process, along with the comparatively low level of both government and private funding on the research, development, and commercialisation pf potentially valuable new products and processes.

I continue my exploration of the structural barriers to innovation in Chapter 9*, Structural Barriers to Innovation: Geography, People & the Valley of Death*. Three structure oriented sub-themes emerged from the interview process. Many participants claim that the geographical size of the nation and poorly connected university precincts make formal and informal face-to-face interaction difficult. They also say Australia cannot maximise its intellectual expertise due to a lack of people with both industry and academic expertise, as well as an ongoing loss of early to mid-career scientists. Finally, participants claim funding and regulatory deficiencies hinder the translation of late-stage knowledge and prototypes into commercial products.

In the final recommendations chapter, I draw upon material from these four themes. However, I present the recommendations under the headings of: **Continuity, Funding, Collaboration**, and **Translation Environment**. These headings reflect potential points of intervention, based on the major findings from the interview data, the data sources discussed above, and the key insights of the NIS literature.

Reflections on the methodology

There are limits to the effectiveness of individual methodologies when dealing with complex systems such as the one Australia relies upon to develop and commercialise its applied science. Earlier in this chapter, for instance, I noted that while quantitative techniques provide critical facts that reveal much about the effectiveness and nature of the country's innovation system, they fail to provide insight into the human dimension of the nation's method of scientific discovery and development.

That human element is critical. Australia's innovation system, like that of any nation, is more than a set of structural components, bound together by policies, priorities and programs established by political leaders. People are the players, the participants operating within the system. The implication is that to understand not just the structure but the drivers and dynamics of the system as fully as possible, it is necessary to view the innovation system and process from the stakeholders' perspective. An extended case study, developed, conducted and analysed using qualitative methods, is a useful tool for doing just that.

This is why I adopted a mixed methodological approach which involved comparing and contrasting findings from my case study and the text-based sources. This approach enabled me to obtain as much information as possible about the how Australians engage in the iterative, intensely human process of innovation, as well as the context in which they engage in this activity.

Together, quantitative and qualitative findings helped reveal the structural and interpersonal strengths and weaknesses of Australia's innovation system. With that information in hand, I was able to identify possible points of intervention around which to structure my recommendations for governmental policy makers and leaders who manage emerging fields of complex scientific and biomedical research. The four headings of **Continuity, Funding, Collaboration**, and **Translation Environment,** reflect this process. Key recommendations based on these findings address identified barriers to innovation.

Still, as with qualitative and quantitative analytic techniques on their own, any single analysis based on a mixed methodology is limited. Work such as this thesis should be complimented with other systematic analyses, founded on other multi-sector case studies. With each addition to the intellectual pool the true picture of the strengths and weaknesses in Australia's innovation system will become clearer and more useful to policy makers, experts and politicians seeking to boost the nation's innovative productivity.

In addition, I recognise that other weaknesses may remain. My interview data clearly has omissions from the five people that refused to be interviewed. I was, however, able to speak with others who represented their sector of the innovation system. This is clearly a difficulty of working with, and generalising from, one case study.

Finally, my personal experience may have influenced my approach and findings. As noted earlier in this chapter, I came to this problem after working for many years as a science journalist and broadcaster. Bias and preconceptions are potential sources of weakness. To that end, I adopted the methodological approach of this chapter, in order to minimise my biases and preconceptions through the methodical collection of data, careful interviewing techniques, and inductive thematic analysis, all grounded in the social science literature on qualitative research methodologies (e.g., Bernard, 2006; Braun, Clarke, & Terry, 2014; Minichiello, Aroni, Timewill, & Alexander, 1995; Patton, 2002; Pope & Mays, 2006; Ziebland & McPherson, 2006, p. 407).

It is my hope that the strengths of this thesis outweigh the weaknesses. I hope that my findings can be used to advance science and innovation policy analysis in Australia, and provide useful ideas to politicians, policy makers, researchers, and those in the private sector who want to take new science-based products and ideas to market.

Chapter 5: The Revised History

Introduction

As with most historical narratives, the story of Australia's quest for the bionic eye has two versions. One is official, based upon publicly available documents. I told this story toward the end of Chapter 3, *The Bionic Eye.* The other is unofficial, told off-the-record by participants and close observers. Both have merit. The official version forms the historical skeleton of the story. The unofficial version fleshes it out, revealing the professional stresses and interpersonal strains of working within the fragmented, ever-changing innovation system described in Chapter 2, *Innovation in Australia*.

Because the revised history involves so many individuals and so many events, I have listed the key participants in Appendix 9 and summarised important developments in Appendix 10. Appendix 10 highlights key advances in bionic science globally, from 2002 when the US company Second Sight began the first clinical trial of a bionic eye, to 2016 when French firm Pixium Vision began multi-centre, multi-national clinical trials of its prototype. No Australian organisation has begun clinical trials. Further, in April 2017 Second Sight announced it has expanded sales from the European Union, the UK and the US into Asia.[86]

What follows is a 'revised history' based on information from the public record and from one or more participant interviews and follow-up e-mails. It traces developments and interpersonal relations which shed light on the structures and processes driving this case study.

In the beginning

The first and most obvious difference between the official and unofficial histories is that the story of Australian bionic eye research does not begin in April 2008 with Prime Minister Kevin Rudd's Australia 2020 Summit. Australian research on a visual prosthesis began in earnest nearly a decade earlier when former Cochlear Ltd engineer Gregg Suaning began a doctorate at the University of New South Wales (UNSW). This brought together UNSW biomedical engineers Klaus Schindhelm and Nigel Lovell, and

[86] See http://investors.secondsight.com/releasedetail.cfm?ReleaseID=1021237

UNSW ophthalmologist Minas Coroneo as his supervisors, forming the core of what I call the Sydney group.

As my interviews reveal, tensions within the group grew when physician Vivek Chowdhury arrived at UNSW to do a doctorate with Coroneo and University of Western Sydney anatomist Jim Morley. Initially, the Sydney group, including Chowdhury, worked together, but soon disagreements arose over what type of technology and approach to use in developing a bionic eye. Essentially, the engineers wanted to design a larger more ambitious system than the ophthalmologists who argued for a modest implant, incorporating off-the-shelf technology developed by Cochlear Ltd.

Participants also describe emerging disagreements over intellectual property within the Sydney group. Efforts by UNSW university officials to dampen the growing antagonism caused more friction, resulting in the formation of two Sydney-based groups, which I call the UNSW group and Prince of Wales (POW) group. The UNSW group was driven by the engineers, and the POW group, by the clinicians. Both groups began seeking separate funding and different collaborators.

Meanwhile, recognising advances in US and European visual prosthesis research, as discussed in Chapter 3, and encouraged by Australia's success with Cochlear's hearing prosthesis, biomedical and computer engineers in Melbourne began discussing joint projects. For example, a year before the 2020 summit, Melbourne University (MU) engineer and Dean of the School of Engineering Iven Mareels[87] organised a round-table to consider bionic eye collaboration. Melbourne-based scientists also participated in a similar meeting in Sydney, involving the UNSW group.

By mid-2007, interest in bionic eye research had spread beyond the laboratory. Deans like Mareels were talking to vice-chancellors such as MU's Glyn Davis, according to interviewees. Meanwhile, organisations including Melbourne's Centre for Eye Research Australia (CERA) and National Information and Communication Technology Australia (NICTA)[88], headquartered in Canberra, were seeking funds and pursuing collaborations.

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87 Mareels currently serves on the BVA Board.

88 NICTA has since merged with CSIRO under the name Data61.

Evidence that interest in bionic eye research was becoming widespread, especially in Melbourne, was reflected by the fact that interviewees said that NICTA head David Skellern commissioned John Parker -- former Cochlear Ltd chief technology officer and executive director – to develop a strategy for a consortium, aimed at building a bionic eye.

Parker did so, identifying technical and performance hurdles. But when he assessed the economic viability of the project, Parker concluded it could not be funded by the private sector. The global market for a bionic eye was too small without rebates from health insurance agencies. As well, after conducting a Quality of Life Adjusted Year[89] (QALY) analysis, Parker[90] calculated those agencies were unlikely to reimburse patients for the device. He concluded the sale price needed to compensate for development and commercialisation costs would outweigh the accepted cost per QALY.[91]

Researchers and stakeholders such as consultants and university officials began lobbying politicians and government advisers for research funding for both proposed and existing bionic eye projects. My interviews show that lobbying intensified following the February 2008 announcement by Prime Minister Kevin Rudd for a summit: he would ask 1000 of the "best and brightest brains" to develop a long-term strategy – a 2020 vision – for the nation's future. Rudd's two-day national think tank, to be co-chaired by himself and Glyn Davis[92], would grapple with ten areas of strategic

[89] A quality-adjusted life-year (QALY) takes into account both the quantity and quality of life resulting from healthcare interventions. It is the arithmetic product of life expectancy and a measure of the quality of the remaining life-years. See http://www.medicine.ox.ac.uk/bandolier/painres/download/whatis/qaly.pdf. Still, there are medical devices developed and commercialised with little regards for potential profitability.

[90] In April 2008 Parker declined an offer to head what became BVA. Today, he heads Saluda Medical, a NSW-based biotechnology firm specialising in pain management technology.

[91] See http://www.scientificamerican.com/article/knocking-on-heavens-door-the-business-of-livesaving/ for the contradictory story of the development of the pacemaker in the US. Profit did not drive the development and commercialisation of the device.

[92] Rudd and Davis first met when they lived and worked in Queensland. See this short biography of Rudd from 2003. http://www.theage.com.au/articles/2003/04/17/1050172703137.html.

importance, from the economy and infrastructure to the arts, the future of government, and health.[93]

Although Rudd had not flagged bionic eye research in his announcement, efforts to bring the topic to his attention, directly or indirectly, escalated, according to interviewees. For instance, engineer and former biotechnology chief executive officer Colin Sutton began discussing the potential of bionic eye research with his contacts on behalf of scientists with the UNSW group and MU.[94]

Data from interviewees and e-mails with participants show others were also working their networks in Melbourne. Among them was MU engineer Tony Burkitt. He hired business consultants to review Parker's analysis and develop another business plan. This work concluded that commercialisation was viable. According to interviewees, Burkitt discussed the matter with MU Vice-Chancellor Glyn Davis who subsequently discussed the bionic eye with Rudd prior to the 2020 summit.

The Australia 2020 Summit

As discussed in Chapter 3, the impetus for the bionic eye initiative was the 2020 summit. However, according to my informants, while ideas were supposed to come from the floor, a bionic eye project had not been discussed at the Health Working Group, co-chaired by Health Minister Nicola Roxon and Queensland Institute of Medical Research director Michael Good. Instead, as Good was preparing his closing statement about the group's deliberations, Roxon presented the idea in a document she identified as a submission from the public.

The provenance of this document is unknown, but it seems likely that it had been developed within Rudd and/or Roxon's departments, building on the report commissioned by Burkitt and ideas presented to Rudd by people such as Davis. This fits with the claim from interviewees that, prior to the summit, Rudd had already

[93] Other areas include environmental issues, e.g. population, sustainability, climate change and water; rural Australia; strengthening communities; indigenous Australians; and international relations (Davis, 2008).

[94] Sutton later became Deputy Chair of the BVA board and chair of Bionic Vision Technologies, the commercial arm of BVA. He has retired from both positions and now works as a private consultant and is a director of UNSW Innovations.

determined that the government would fund a MU-led consortium and present it as a practical outcome of the summit.[95]

The implication is that the idea that the government should support bionic eye research had worked its way up the chain -- in fact, up several chains -- from researchers to university officials and consultants to Rudd who passed it on to Roxon who presented the idea to Good as an outcome from the working group. Although the bionic eye had not been discussed by the working group, Good agreed it could be an example of how to commercialise medical research, a topic that had been discussed. He was, therefore, willing to accept it as a recommendation from the group.

As was noted in Chapter 3, I was the Science Writer for *The Australian* newspaper at the time of the summit. The Monday following the event I rang around to find out what, if anything, was happening with bionic eye research in Australia. In less than two hours I learned of the work of the POW group, as well as the international competition to get a product to market.

In the next day's newspaper[96], I reported Minas Coroneo's claim that the POW group had developed a basic prototype for less than $100,000, had conducted animal trials and human sensitivity tests, and that they were going to an early trial with a single volunteer when key components arrived from Cochlear Ltd. The group was excited the summit Health Working group recommended that $40 million be allocated to build a bionic eye and, thus, the possibility of obtaining $100,000 to conduct a Phase One clinical trial. I also reported that Good and the working group knew nothing about the POW research.

I did not know it at the time, but interviewees report that my story – prominently displayed on page one of the paper -- inadvertently scuttled Rudd's plan to announce that in response to the Australia 2020 Summit a MU-led consortium would receive $40 million to build a bionic eye.[97]

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[95] This claim remains an allegation by interviewees and has not been confirmed or denied by Rudd.

[96] Dayton, 2008a.

[97] For publicity purposes governments often release press statements about 'announceables', i.e. funded projects or policies and activities that put them in a favourable light. It was important to Rudd that Australia's 2020 Summit appear to be more than an expensive 'talkfest'.

Politicking

The prospect of gaining federal funding to support bionic eye research was now realistic, thanks to Rudd's announcement. Quickly researchers and organisations began jockeying for political attention, both behind-the-scenes and through releases to the national media. As the bionic eye story kept running, reporters continued to cover developments in Australia and overseas. The result was an unofficial race. The primary contenders were MU and its collaborators, including the UNSW group, and the POW group.

But Melbourne had the political lead. For instance, in early July[98] I wrote a piece confirming that Nicola Roxon had met with representatives of the Bionic Ear Institute (BEI). The topic was the establishment of a $40 million Medical Bionic Institute which would develop a bionic eye. While the institute never materialised, the discussion illustrates the prominence and political influence of the Melbourne biomedical community.

Meanwhile, in California an Australian doctoral student named Adrian Rowley heard about Rudd's plan to build an Australian bionic eye. At the time, Rowley was working with Mark Humayun at the Doheny Retina Institute based at the University of Southern California (USC). As noted in Chapter 3, Humayun had collaborated on research to develop a bionic eye for roughly 16 years, both at the university level and then with Second Sight, once the company was established.

Thinking of returning to Australia, Rowley visited Sydney and Melbourne, suggesting to potential employers that he could contribute to bionic eye research. Concern was expressed to him about potential conflict over ownership of patents. As a result, there were no job offers. He returned empty-handed to California. But Rowley and his colleagues kept an eye on developments.

Back in Canberra, Science Minister Kim Carr issued a press release on 22 July 2008 in which he "congratulated" frequent MU collaborator Bionic Ear Institute (BEI)[99] for hosting the upcoming inaugural Medical Bionics Conference, funded by Carr's

[98] Dayton, 2008b.

[99] Renamed Bionics Institute in 2011.

department. The press release highlights the productive relationship between the minister, and the scientific community within his Senate seat of Victoria.

The conference was held 16-19 November 2008 in Lorne, Victoria. Chaired by BEI director Rob Shepherd, it included sessions on neural and retinal implants. Speakers chosen for those sessions reflected the influence of the Melbourne biomedical community. Nearly all presentations were by Melbourne-based or affiliated scientists, including MU's Tony Burkitt, and Nigel Lovell of UNSW. Biomedical engineer Thomas Stieglitz, with Germany's University of Freiburg, also participated.[100] Interviewees confirm that members of POW group were not invited to speak and did not attend.

The quiet review

Kevin Rudd clearly had a delicate political problem. A 'good news' year-end announcement that a Melbourne consortium would be given $40 million to build an Australian bionic eye would likely prove controversial, given the entry of an unanticipated research team, the POW group, and the ongoing media coverage of national and international bionic research. The situation needed to be handled carefully.

The solution: an expert review. Bypassing the science and health ministers, in December the Department of the Prime Minister and Cabinet asked Chief Scientist Penny Sackett to arrange a review panel and report the findings to them. Interviewees claim that the independent reviewers evaluated the informal submissions and information brought previously to the government's attention by Melbourne interests and the POW group, as part of their efforts to garner political attention. It is uncertain if representatives of either group were informed of the review process once it was initiated. I was informed that Carr knew nothing about it.

Sackett quickly set-up a committee of four experts. With the help of her office they had one week to review the unsolicited MU and POW submissions. These reflected the early disagreement between the original Sydney group which had split into the UNSW and POW teams. The MU proposal was ambitious, while POW'S modest proposal was based on existing Cochlear technology.

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100 Between October 2009 and February 2010 Stieglitz was Professorial Visiting Fellow with the UNSW Graduate School of Biomedical Engineering.

During my interviews, I learned that the committee was critical of the Melbourne proposal, saying that despite the team's technical expertise it was unclear how they would achieve their promise to deliver a device of such high resolution that people could read a book. In contrast, they concluded the POW group might well deliver a product, a simple one able to help people with retinal diseases navigate more easily. I was advised this was not the expected outcome. No public announcement was ever made about the review or its recommendations.

The special initiative

In the New Year, Rudd handed the bionic eye project to his science minister. Carr was tasked with finding a way to fund it.

While conducting my interviews, I was told that Carr was advised that the National Health and Medical Research Council (NHMRC) was not able to fund projects of this type and that there was no support for such projects from the Department of Health. So, Carr looked to the Australian Research Council (ARC) Special Research Initiatives scheme as a mechanism for evaluating and organising the distribution of funds for the initiative. Along with his advisers, Carr worked with ARC Chief Executive Officer, Margaret Sheil and her colleagues to establish the ARC Special Research Initiatives Research in Bionic Vision Science & Technology, the bionic eye initiative.

On 22 April 2009 Carr and Roxon announced the Rudd Government would dedicate $50.7 million over four years for the development of a bionic eye, or "retinal prosthesis", as the press release called it. National and international experts would be involved in selection of the grants to be awarded.[101] Winning teams would be expected to include experts in development and commercialisation of medical devices.

The race was on. Interviewees say researchers, organisations and their advocates began pulling together participants and ideas for funding applications. And not just in Australia. From California, Second Sight and USC sounded out potential collaborators in Melbourne and Sydney. Adrian Rowley contacted the then Queensland Trade

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[101] Members of the Selection Advisory Committee included Dr Mike Hirshorn, Director, Four Hats Capital Pty Ltd (Chair) and later the independent chair of BVA; Professor Philip Luthert, Institute of Ophthalmology, Director and Head of Division of Pathology, University College London; Professor Mike Calford, Deputy Vice Chancellor (Research), the University of Newcastle; and Mr David Money, Biomedical Engineer (retired). I was told during interviews that they had no knowledge of the previous year's quiet review.

Commissioner, Peter Beattie, about a joint US-Queensland proposal. Beattie met the Second Sight-USC principals while he was in California.

Interviewees reveal that in June, Mark Humayun sent Rowley to Australia to follow-up on initial discussions between Queensland research organisations, USC, Second Sight, the POW group, and Beattie. There was strong interest from Queensland University of Technology (QUT), and mixed support from the University of Queensland (UQ), as well as interest from the POW group. Melbourne expressed no interest in collaborating with Second Sight and company.

Through interviews and follow-up e-mails, I learned that while some researchers suspected a preferred team had already been selected, Beattie encouraged the institutions to collaborate and submit a proposal. Although it was initially involved in the proposed US collaboration, the POW group withdrew in recognition of past support from Cochlear Ltd which was in dispute with Second Sight co-founder Al Mann over intellectual property and business tactics. This ultimately meant that a Queensland-US consortium applied for ARC funding, while POW group formed its own consortium and proposal.

Not long after his Australian visit, interviewees claim Rowley spoke briefly with Carr at a scientific conference in Chicago. Carr expressed his opinion that Australia could, on its own, build a bionic eye cheaper and faster than a team including Second Sight and its USC collaborators – this despite the Californians' head start on the research and previous $200 million in funding. While Carr had no input into the selection of the finalists and eventual winners of government support, the incident reveals the government's strong belief in a 'made in Australia' bionic eye.

The commitment to Australian research was reflected, perhaps coincidentally, by the composition of the winning consortia. All the program leaders and chief investigators on the winning applications represented Australian organisations. Similarly, all the original collaborating and partner organisations were Australian. This contrasts with the make-up of the applications from Queensland and the POW-led Group. I have not sighted the four other applications. The ARC declined to provide them, citing confidentiality.

In Sydney, racing to meet the July 29 deadline for submitting applications, interviewees say the POW group experienced internal conflicts. One of the lead researchers, Vivek

Chowdhury, was working overseas at the time and was not affiliated with UNSW, the higher education institution which would administer the funding under the application. When the application was lodged, listing him not as a chief investigator but as a partner investigator, interviewees say Chowdhury was offended. He wrote to the ARC, withdrawing from the application. As a result, the ARC disallowed the application, thereby scuttling the POW consortium's opportunity to compete for funds.

Not surprisingly, mutual recriminations followed, and Chowdhury and Coroneo severed contact. The POW group had eliminated itself from the competition, leaving MU the clear front runner. I was told by an interviewee in a follow up e-mail that during a meeting about their application, members of the MU bid learned that the POW application had been disallowed. It is not clear how the information was obtained or by whom.

In December, the funding decisions were announced. The Melbourne bid was one of three shortlisted bids, and one of the two which would be funded. Details of the third and unfunded group were not revealed. The Melbourne consortium, later named Bionic Vision Australia (BVA), received $42 million over four years. A Monash University consortium, soon to be named the Monash Vision Group (MVG), had formed in response to the ARC call for applications. It was awarded $8 million, also for the period 2010-2013. As discussed in Chapter 3, BVA was funded to work on two types of implants to stimulate the retina, a "wide-view device'' and a "high-acuity" device.[102] Monash would work to develop a visual cortex implant.

Getting on with the job

With funding commencing in 2010, BVA and MVG got to work. Both consortia had to recruit doctoral students, postdoctoral fellows and researchers to do the hands-on work. They also needed to finalise organisational, governance and communication structures, as well as legal agreements.

For MVG this was a more straightforward task than it was for BVA. MVG partners were all based in Melbourne: engineering, computer scientists and medical researchers from Monash University and Alfred Health, and industry partners Grey Innovation and

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[102] BVA's "wide-view" device was a suprachoroidal implant that would assist patients experiencing difficulty with light perception and basic mobility. The "high-acuity", retinal implant would provide central vision to assist with tasks such as face-recognition and reading large print.

MiniFAB. Further, the consortium was beginning their cortical prosthesis project from the ground up as a single team.

In contrast, BVA had chief and partner investigators from six institutions in Melbourne, Sydney and Canberra.[103] The group had an additional challenge in that one of their chief investigators, Greg Suaning from UNSW, was continuing a separate project which he had had begun years earlier with Nigel Lovell, a wide-view prosthesis design, but now under the BVA banner. In contrast, his Melbourne-based colleagues were in very early stages of work on a high-acuity device and on their own contribution to a wide-view implant, a less powerful and smaller device than the UNSW effort. Melbourne and Sydney-based team members conducted research on these separate devices at their own facilities.

The size and diversity of the BVA collaboration required a rigorous organisational structure to hold the endeavour together. As inaugural BVA Chairman, David Penington had consortium oversight. Penington (a former MU Vice-Chancellor and former Chair of Cochlear Ltd) worked with the BVA Director, Tony Burkitt (a MU neuro-engineer) and his Executive Team, along with a Board of Directors representing member groups. In turn, the Board created three Board Committees: the Scientific Advisory Committee (SAC), Risk and Audit Committee, and Research Management Committee.

Altogether, the total number of BVA staff, students, management and various Board members vary, but hover around 180. Separately, a privately held company, Bionic Vision Technologies, was established in 2010 to hold and commercialise licenses to the intellectual property developed by BVA. In 2011 BVA appointed an Intellectual Property Manager.

MVG has a similar though slimmer governance structure: an Advisory Board with an Independent Chair[104], and a Steering Committee with its own sub-group, the Commercial Committee. Monash engineer and MVG Director Arthur Lowery heads the

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[103] The BVA application had participants from MU, UNSW, the University of Western Sydney and the Australian National University. Partners included National ICT Australia (now absorbed into the Commonwealth Scientific & Industrial Organisation), the Bionic Ear Institute (now the Bionics Institute), and the Centre for Eye Research Australia. The Royal Victorian Eye and ear hospital joined in 2010.

[104] Founding Independent Chair Mike Hirshorn died in 2011 and was replaced by Monash University's David De Kretser who had recently stepped down as Governor of Victoria.

Executive Team. He also sits on the Advisory Board and the Steering and Commercial Committees. For commercialisation purposes MVG, through industry partners MiniFAB and Grey Innovation, created the company Gennaris Pty Ltd in October 2013. The team has roughly 73 members.

Once both groups had their newly formed structures were in place, some BVG scientists continued work on the bionic vision projects they already had underway, while other BVG and MVG scientists set to work, designing and developing prototypes for testing.[105] By 2013 MVG had made progress on the component design, as well as the manufacture, testing the integration of these components into a working visual cortex prototype. In 2015 MVG announced it would be ready to begin clinical trials in 2016. In 2017, this date was postponed to 2018.

BVA also made advances with its high-acuity and two wide-view devices. In 2012 BVA began a two-year laboratory trial, with three volunteers, of an early version of the Melbourne arm's wide-view device. In 2015 the UNSW arm of BVA began an animal trial of its more powerful wide-view prototype and plans to begin a 3-year trial of a revised version of the device. The UNSW high-acuity device is in preclinical development.

With so many participants in different locations and with different projects, it is not surprising that interviewees report that, over time, stresses built-up within BVA.[106] Disagreements arose between some UNSW and MU researchers working on their different wide-view devices, as well as between some researchers and the Board of Directors. Tensions came to a boil in 2013 after Science Minister Kim Carr announced a one-year extension to bionic funding: $9.9 million to BVA and $1.9 million to MVG.[107] The question for BVA was how to allocate the funds within the consortium.

The matter was the subject of an August 2013 teleconference of BVA's SAC, according to interviews and follow-up emails. The committee, under the chairmanship of

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[105] It is not the purpose of this chapter to cover scientific progress in detail, rather it is to identify trends and events that reflect the innovation processes within BVA and MVG. Technical information is available from BVA and MVG annual reports.

[106] Despite internal pressures at BVA, the BVA and MVG chairs worked together to identify government funding sources which might be tapped to extend their consortia at the end of the original 4-year ARC support.

[107] 12-14 February 2013 an ARC panel reviewed MVG and BVA. Draft results were released to groups in April, but were never made public. I have not sighted reviews for either group.

Australian National University systems engineer Brian Anderson, was strongly of the opinion that the funds should go only to Melbourne-based researchers. They reasoned that the UNSW arm had failed to meet its milestones, whereas the Melbourne arm was on track and should be supported to the commercial-ready stage.

The committee also expressed concern with the performance of BVA Director Tony Burkitt. It was decided that the SAC chairman send a confidential recommendation to BVA chairman, David Penington, recommending the director be replaced. On receiving the recommendation, Penington called a meeting of the BVA directors to consider the matter. Penington then sought further advice from Vice-Chancellor Glyn Davis. No further action was taken regarding the recommendation that Burkitt be replaced after Davis informed Penington that such a move would prompt an unwelcome public review of BVA by the ARC.

The SAC recommendations regarding funding were poorly received by the BVA board, interviewees say. The Board rejected them at its September quarter meeting. Penington felt an alternative research and development plan that Burkitt had presented to the board was not viable. He, therefore, resigned when the board accepted Burkitt's plan. Colin Sutton took over as BVA's interim chair, with Mark Hargreaves (MU Vice-Chancellor Research Partnerships) taking on the role in January 2014.

Anderson retired from the SAC later that month. Biomedical microsystem technology expert Thomas Stieglitz, with Germany's University of Freiburg, now chairs the SAC with UNSW's Nigel Lovell serving as the committee's convenor.

This is the structure the BVA consortium now follows as it continues to work towards commercialisation of its wide-view and high acuity devices. MVG continues with its original structure in place.

Where are they now?

By the end of 2015, ARC funding to the bionic eye Special Research Initiative ceased. The initiative had provided a total of $59.9 million to BVA and MGV. To date, neither group has a commercial-ready prototype, although each continues research and development with additional support obtained from alternative sources.

Both consortia have sought and continue to seek funding to permit ongoing development of their prototypes to the commercial-ready stage. Although both are behind their international competitors in terms of clinical trials and the government approvals needed to sell their implants, BVA and MVG argue their designs will, in the long run, prove safer, more effective and simpler to manage medically than those near, or already on, the market.

Summary

The story of Australia's bionic eye initiative began, as do many research enterprises, with individual researchers pursuing work they believed had clinical and commercial merit. As their work progressed, they began exploring collaborations to extend their research and enhance their funding prospects.

As interest in Australian bionic research grew, spurred by media interest and international advances, so too did efforts by the researchers to lobby senior university officials, government officials and politicians. Soon after the election of his government in 2007, Kevin Rudd was convinced that funding a bionic eye initiative made good policy and political sense. While apparently not discussed by the 2020 summit's Health Working Group, health Minister Nicola Roxon ensured that it was included as a recommendation from the group. Rudd identified the bionic eye as a practical summit outcome.

The behind the scenes plan of politicians to fund a bionic eye project, led by MU, was complicated by media coverage of the POW group and a scramble by groups to gain public and political attention. After an unpublicised review in 2008, Science Minister Kim Carr announced the ARC Special Initiative in Bionic Vision Science and Technology in 2009.

Competition for the associated $50.7 million in funding was intense between scientists, universities and research organisations. Eventually, two groups were funded: MVG with initial funding of $8 million and BVA with $42 million. As MVG is smaller and began its project from the ground up, it had fewer interpersonal tensions than did BVA. Conflicts within BVA were so intense, the chairman of the board and the SAC chairman both resigned following internal disputes about how to use the additional year of funding offered by the government.

By the completion of the 2010-2014 ARC bionic eye initiative, the federal government had spent nearly $60 million. Research had been supported and students trained, but that was not enough to keep Australia in the vanguard of bionic eye research and development. Neither BVA nor MVG is close to commercialisation.

Their prototypes may become commercial successes in time, but as noted in Chapter 3, the international competition remains ahead and continues research and development. US firm Second Sight Medical Products has received approval to market its Argus II Retinal Prosthesis in Europe and the US, and in 2017 announced it had moved into Asia. Other teams in the US, Europe and now Asia are catching up to the leader, Second Sight, and appear to be ahead of the Australian groups.

The revised history presented in this chapter reveals many of the problems with Australia's innovations system: from scientific isolationism and political interference, to intense competition between researchers and, therefore, weak collaboration. In the following chapters I will explore the thematic analysis of my interviews which helped reveal these barriers to innovation. The focus will be on the structural and cultural factors which participants in the bionic eye initiative identified as barriers to advancing their work and to innovation in Australia.

Chapter 6: Findings: Academic Culture

Introduction

The preceding chapters in my thesis have provided the conceptual and historical basis of my topic, innovation in Australia. They also introduced the bionic eye, the subject of my case study. With the skeleton of my work in place, it is now time to flesh it out with an exploration the thoughts and experiences of people working within the nation's innovation system.

Participants in my case study represent a range of positions within Australia's innovation system, from researchers, project managers and their advisers, to politicians, political advisers and government appointees. Given their differing roles, it is not surprising that their personal experience of the bionic eye initiative varies. So too do many of their opinions about the strengths and weaknesses of the national innovation system.

Despite their divergent perspectives and views, however, common themes emerged from the interview data. For example, the three themes raised most frequently by participants were funding, interpersonal factors, and the political cycle.

A careful analysis of these and other themes emerging from the data I obtained through the interview process[108] suggested two over-arching categories*: Cultures of Innovation* and *Structural Barriers to Innovation*. I will use these two categories as a framework for presenting the findings from my analysis of participant interviews over this and the next three chapters.

In this chapter, *Academic Culture,* and the next, *Culture Clash: the influence of political and industry cultures,* I use 'culture' to mean the values, common understandings, mutual expectations and patterns of behaviour shared by members of a group (Berreman, 1971, p. 544). While I have borrowed this definition from anthropologist Gerald Berreman, I do not use it in a strictly anthropological sense.[109]

[108] For details see Chapter 4: *Methodology.*

[109] Within anthropology the definition of 'culture' is contentious. For instance, where Berreman uses it to describe commonalities within a group, Anthony FC. Wallace promotes the idea that culture is a system for organising the diversity within a group (Wallace, 1962). As Wallace writes,

Neither do I argue there is no disagreement or conflict between members of a culture. There is. Still, members recognise the over-arching values and expectations of their culture. Consequently, Berreman's account is useful in allowing me to compare, contrast and discuss data obtained from participants working in different components – cultures -- of Australia's innovation system.

Given that I look at internal dynamics within, as well as between cultures I also use the term 'sub-culture'. Here, I refer to smaller groups embedded within a culture. For example, I view disciplines such as engineering and ophthalmology as sub-cultures of academic culture. While members of sub-cultures recognise the broader values and expectations of the wider culture, they also develop ways of organising their behaviour, values, and expectations that are specific to their group.

Two further chapters -- *Structural Barriers to Innovation: Politics and Funding* and *Structural Barriers to Innovation: Geography, People and the Valley of Death* -- cover impediments to productive innovation built into Australia's national innovation system. Many structural barriers identified by participants are practical consequences of cultural features of the innovation system. Conversely, the structure of Australia's innovation system influences the nature and impact of cultural values and behaviour.

Some themes, such as funding, could be canvassed in many of the findings chapters. In such cases, I discuss aspects of the theme that pertain to each chapter. For instance, participants report that intense competition for research funds is a significant part of academic culture, often pushing researchers to collaborate on grant applications, only to go their own way once they have been funded. Others say Australia's funding system is ill-suited to large academic/industry collaborations such as the bionic eye initiative. The funding system thus poses a structural barrier to innovation, they claim.

The themes that emerged from the interview data are consistent with my analysis of the nature and structure of Australia's innovation system, as derived from texts and archival material outlined in earlier chapters. However, it is important to note that some 'facts' presented by participants are not technically correct. To illustrate, several participants incorrectly claimed that it is impossible to change chief investigators after an Australian

"anthropologists have continued to work with the methodological problems of measuring the extent of sharing and diversity" inside groups (Wallace, 2009, p. 251). Details of this theoretical debate are beyond the scope of my thesis.

Research Council (ARC) proposal has been funded. Although incorrect, this belief influenced the way they managed their grant funding and team composition.

Regardless, the body of interview data provides insight into the complex interpersonal relations that operate within the nation's innovation system. Such data are invaluable to a primary objective of this thesis -- developing recommendations for boosting the nation's innovation output.

Academic culture

In 1988 French sociologist Pierre Bourdieu published *Homo academicus.* In his often witty, often impenetrable book, described as a "self-analysis", Bourdieu examines the socio-economic background, conflicts, collusions and political activities of French academics. With a nod to Bourdieu's insider assessment of his professional world, in this section I present an outsider assessment, based on participant observations and experiences of the same world, academia.

I identify key features of Australia's academic culture, and describe their effect on innovation. These features, configured here as themes, emerged from my analysis of participant interviews, and go far to pinpoint barriers to innovation within academic culture. The themes I discuss here are: Funding, Metrics, Isolationism (Silos and Turfs) and Interpersonal Factors.

<u>Funding</u> is at the heart of academic culture. Researchers need financial support to conduct their work, alone or in teams, while university administrators rely upon external funding to run their institutions. There is constant pressure upon administrators and researchers alike to ensure they identify and tap sources of financial support.

Along with funding, <u>metrics</u> are a central and pressing feature of contemporary neoliberal academic culture. Researchers gain funding, respect and promotion based upon their professional track record. In turn, their track record is gauged primarily on their publications, along with their ability to attract government grants and other financial support.

<u>Isolationism</u> is a consequence of the pressures of contemporary academic culture. In this context, it is a tendency to restrict interaction with others. In this section I discuss two

forms of isolationism: silos and turfs. Silos are informal associations found in organisations. Turfs are specialist research topics pursued by individual scientists.

Finally, interpersonal factors such as personality, professional goals and communication skills can generate productive or unproductive collaborations.

I begin with funding because, as noted above, it is one of the themes most frequently mentioned by participants from all positions within Australia's innovation system.

Funding: "Once you start constraining the resources it's the classic law of the jungle" (Participant 11)

Participants' daily academic activities are shaped by the understanding that funding – from all sources -- is scarce. In a comparative study of physics research funding in Australia and Germany, Technical University of Berlin sociologist Grit Laudel notes, the situation is worsened because "shrinking university budgets" are no longer sufficient to support staff research, as they did in previous years (Laudel, 2006a,p. 489).[110] According to Participant 17, one reason that university budgets continue to decline is that: "Both sides of politics just want, tend to see universities as a cost, rather than an investment".

Researchers must, therefore, seek "external funding" from bodies such as the Australian Research Council (ARC) and the National Health and Medical Research Council (NHMRC) or from industry. Laudel writes that this reality places researchers "in a resource environment that is characterised by scarcity, competition and continuous evaluation" (Laudel, 2006a, p. 489).

For participants, this is a persistent concern. As Participant 24 said of funding from government sources, "there is only a certain amount of money going around".[111] Grant success rates are indeed low. Competition for any level of funding is fierce with typical success rates of 15-18 percent.[112] According to participants, industry funding is even

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[110] While funding is a significant issue, in this chapter the focus is on the effect of funding regimes on academic culture.

[111] I will discuss funding levels further in Chapter 8, *Structural Barriers to Innovation.*

[112] The average success rate for applicants to the ARC's 2015 major grants round is 18%. See: http://www.theaustralian.com.au/higher-education/arc-success-rates-steady/news-story/56c41e0ada4efe826039e1059589bcff. In 2014 the National Health & Medical Research Council success rate was 15%. https://www.nhmrc.gov.au/media/newsletters/ceo/2014/getting-ready-2015-project-grants-funding-round-applying-funding-when-suc.

more difficult to secure, largely because industry is reluctant to invest in projects with uncertain outcomes, as noted in Chapter 2, *Innovation in Australia*. Participant 10 commented:

> Our smaller companies are most reluctant. The truth of the matter is that only a minority of firms in fact invest in innovation.

The result of consistently limited funding is clear to researchers. Given that the success of academic careers depends in good part upon securing funding, competition is ongoing. According to Participant 9, the result is that "There's always competition for funding". Since large grants are few and far between, Participant 14 noted, "It's usually a lot of squabbling over very small amounts of money".

In fact, several participants observed that researchers are often so keen to secure funding that they do not explore potentially rewarding problems or projects that lie outside the research area for which they have previously received funding. That is so, they suggested, as extending into a new area creates greater uncertainty about future funding outcomes when compared to pursuit of an already successful research topic.

This uncertainty raises the possibility that a researcher's funding track record and output of papers may be disrupted, risking access to further funding and, thus, threatening their professional security and career path.[113] The observation fits neatly with results of a survey conducted by US public policy consultant Daryl E. Chubin and Edward J. Hackett, a sociologist at Arizona State University. They found that between a third and a half of scientists whose proposals were initially denied funding stopped pursuing that particular line of research (Chubin & Hackett, 1990, pp 60–65).

By its very nature the bionic eye initiative intensified this inherent competition. That is so because it was an ARC Special Initiative which offered a comparatively large amount of funding[114] in a little-studied field. It triggered a dash for cash, an opportunity for researchers to support their individual work, and university officials, their institutions. Participant 11 summed up the situation:

> That [situation] is going to be highly competitive, and the players will know that this is a one-off … It could reduce the level of collaboration and trust because a very small number of teams are fighting for what they see is

[113] I will expand this issue in the following section on metrics.

[114] Initially $50 million over four years.

> probably their only chance, perhaps in their career, you know, to get that kind of money.

Participant 11's point is underscored by the fact that several[115] participants noted that effective collaboration was not necessarily their top priority when selecting potential partners with whom to apply for bionic eye funding. They said their choice of collaborators was shaped by funding criteria, particularly what they perceived as the necessity to have people with "good track records" on their applications[116] (Participant 19).

Respondents claimed grant review committees respond favourably to funding proposals containing the names of established scientists with a strong history of grants and publications, and less favourably to applications with participants who may be well suited to a project but with less extensive track records. Participant 19 referred to this approach by grant review committees as "snobbery", emphasising that their group resisted and chose collaborators for their grant proposal on the basis of "what we needed in terms of expertise", rather than on track records alone.

Participant 8 went further: "[Grant review selection] is not done on merit. It's done on who owes who a favour". Such perceptions may or may not be accurate, but they reflect the emotional pressure participants feel when selecting other investigators to appear on a grant application, especially one with multi-millions of dollars on offer.

According to many participants, then, the attractive ARC funding available for the bionic eye initiative pushed them to sound out potential collaborators, not necessarily because they wanted to work with them, shared the same research goals or felt they would bring desirable expertise to their current work, but as a means to increase the chance of their proposal receiving some or all of the available funding.

However necessary this approach may have appeared to researchers seeking funds, the strategic process of selecting partners on the basis of their track record offers no guarantee that the resulting collaborations will be productive. In fact, it can limit the success of a funded collaboration, noted Participant 7:

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[115] When I say "several" or "many" participants, I mean that the concept has been raised in one form or another by three or more participants. As I have conducted qualitative, not quantitative, research, I think this approach best reflects the experiences and views of participants.

[116] Under certain funding schemes, granting bodies such as the ARC and NHMC specify how much weight is given to applicants' track records.

> These people are not committed and are not necessarily interested in achieving that project outcome. They're committed and interested in investigating their area and investigating outcomes in their field and in their interest.

Participant 16 made the same comment, but from the perspective of a scientist asked to add their name to a bionic eye funding proposal developed by other investigators, as opposed to a chief investigator seeking collaborators for a proposal that they would lead:

> Yeah, there were collaborative partners on the grant, but … in practice I don't know how collaborative they really were, and how much actual input into the proposal they might have had. I mean, I did get the feeling that even the involvement from myself and [name withheld] at [institution name withheld] was really helping to bolster their chances of getting the grant awarded, rather than being significant players in the grant itself.

In other words, many participants felt that in cases of strategically-motivated collaboration, the likelihood of achieving the project outcomes is less certain than when researchers come together on the basis of shared interests and goals:

> If you're not interested in getting involved and you're just really after the money, you're not going to get much done [on project outcomes]. (Participant 15)

Another problem arising from such strategic collaboration, driven by competition for constrained financial resources, is that disruptive interpersonal conflict and management difficulties may emerge once a consortium has received funding. Participant 25 noted that this was a particular problem with Bionic Vision Australia (BVA):

> I mean these groups weren't about [collaborating for] commercialisation. These groups were about [funding their own] research.

Participant 26 agreed:

> Essentially, there are groups that compete with each other for funding under other circumstances, sort of agreeing not to compete for the sake of getting that funding, only to turn around and even within that group compete. It's very, very hard to get rid of [this behaviour] unless you control it.

Like Participant 25, numerous interviewees claimed this was the case with BVA, among them Participant 26:

> Everyone was signed-up with the notion of cooperating to the extent that they needed to in order to get the money, but as soon as they got the money they were all going to do exactly what they wanted to do.

In Chapter 5, *Revised History,* I revealed that conflict emerged in BVA, particularly over how the consortium's final year of funding should be utilised: to move the most advanced prototype toward commercialisation or to support each team's research. Participant 18 recalled that the potential for conflict was clear from early days: "Well, we already knew that we were going to have it hard, because everybody had very different ideas on the table".

Ultimately, the Chair of BVA resigned, the head of the Scientific Advisory Committee retired soon thereafter, and the funding was distributed amongst the consortium's research groups. Participant 17 directly mentioned the strains the disagreement triggered:

> Oh yes, it was a difficult period because this large group of scientists both in NSW and Victoria were able people who had their own ambitions and believed passionately in their own projects.

Arguably, the conflict hampered the consortium's success. To date, BVA has not produced a prototype ready to proceed to clinical trials, let alone commercialisation.

Taken together, comments from participants reveal that they believe the ongoing pressure to obtain scarce research funding is a central feature of academic culture. Researchers need money to continue their work, train students and advance their careers. University officials must find funding to support their institution and maintain good working conditions for staff. Competition is fierce even for small grants.

Further, the fight for funding – Participant 11's "classic law of the jungle" -- is seen as detrimental to research outcomes. Potentially productive lines of research may not be pursued if they do not receive initial funding. Researchers seek collaborators strategically because of beliefs or concerns about the grant review process. Even when collaborators win awards, they may clash over use of the funds.

None of these behaviours have much to do with improving the quality of research outcomes, and seem particularly ill-suited to boosting innovative results. As Participant 17 concluded: the university sector is "really very risk averse", and the quest for "large sums of money" is a "big obstacle" to innovation.

Metrics: "How is your career path valued?" (Participant 28)

In any job there must be a mechanism for evaluating the performance of employees, from administrators to zoologists. While the private sector has fewer constraints in their evaluations, publicly-funded organisations such as universities are more accountable.

According to Margaret Jolly, an anthropologist with the Australian National University, the contemporary focus on academic accountability arose during the 1980s with the election of Prime Minister Bob Hawke. The government's expansion of the higher education sector was accompanied by the emergence of a "neoliberal audit culture", Jolly argues. There was, she writes, "a new stress on corporatism, economic efficiency and accountability" (Jolly, 2005, p. 34):

> University Vice-Chancellors were enjoined to act like CEOs of private corporations to instil the values of efficiency and entrepreneurship among their staff… Yet despite the rhetorics [sic] of a small state and reduced state intervention, the federal government increasingly intruded into the internal workings of each institution with a series of auditing practices that monitored the performance of both individual staff and collectivities. (Jolly, 2005, pp 35–36)

The trend, says Jolly, continues. So, the question, "How is your career path valued?" is one all researchers ask of themselves and the system within which they work. In contemporary Australian universities the question invokes specific, audit-oriented answers. There are several elements to these answers which I discuss below. But nearly all participants agreed with Participant 17 regarding the most important audit measure, or metric, used to evaluate of the quality of their work: "At the moment, performance at universities in research is based primarily on publication".

Why is this so? One obvious answer is that the number of publications and the journals in which researchers are published are easily identifiable and quantifiable.[117] Consequently, along with a researcher's success in receiving grants, publication success is the core metric considered when decisions are made about a researcher's promotion, salary and overall career progression.

[117] The metric is generated by determining how many papers researchers have published, how influential the journals are in which they are published, and how many citations each paper received.

It is not surprising, then, that the pressure to publish is intense. It is the "system" and "people will optimise their performance in a system, given a set of outcomes," said Participant 26.

Undoubtedly, scientists are driven by curiosity and a desire to contribute to the body of knowledge in their field, but they must be aware of more practical goals too:

> In academia, the goal is to get a track record and an international reputation, and it doesn't really matter what it's in. And it doesn't really matter whether it had any commercial outcome at all, and nor should it in some cases. (Participant 19)

There are immediate consequences of the emphasis on publication as the central measure of a researcher's performance. Firstly, they feel pushed to publish early and publish often. That is "challenging", as Participant 19 stated:

> [Researchers] want to publish, and they don't want to be beaten to publish papers. And the authorship of papers, they want to be first.

Secondly, like the strategic thinking involved in grant applications, the pressure to publish and publish first can become a logistical exercise in balancing quality and speed. While understandable, Participant 8 said this approach can be taken to extremes:

> Australian scientists, they have the 'salami slice' technique where you get data and you cut it into the smallest amount, and then you publish that. And people end up with 200 or 300 publications, none of which amount to a hill of beans. And so this is the 'safety first' approach.

While not as critical as Participant 8, Participant 28 agreed that although using publications as a primary metric for assessing the work of scientists is straightforward and transparent, it can be a barrier to productive outcomes:

> The current system where we only value academics by the number of papers they push out, the number of students they supervise. That, for me, doesn't foster innovation. That fosters wheel-cranking.

Participant 29, who is not based in Australia, agreed that an emphasis on producing publications hinders scientific advance. This was apparent in the case of the bionic eye initiative which saw overseas consortia commercialise bionic prostheses well before BVA and MVG began early trials with people. That was possible, the participant said, "because we weren't concerned with academic responsibilities".

Further, according to Participant 17, the tendency to rate researchers on their publications trickles up to the university level where it similarly hampers organisational, along with intellectual, creativity:[118]

> When a university such as my own, [name withheld], is finally recognised internationally just on the basis of its publications and the like, then it's hard to get people to face up to the need to change.

Relatedly, institutions wanting to boost their reputation and global ranking in order to attract staff, students and funding, may push researchers to avoid risky projects in order to keep the flow of publications strong. As Participant 16 observed, "that's bad science".

Back at the level of the bionic eye initiative, many participants said the importance of academic metrics to researchers had a direct -- and negative -- impact on progress of their consortium. This is because while the nature of the initiative required participants to work on the creation of prototypes, many felt pressured to produce publications. Likewise, Participant 28 said the project focus on prototypes made the project less attractive, in particular, to many early and mid-career researchers, keen to build an impressive track record:

> If you work on a project like ours, you are basically stepping outside of that pathway for a period of time. And that's potentially a career risk if you want to go back into a traditional university environment. Because on a project like ours where there's this time lag because you have to learn the other disciplines and we have a commercial goal in mind, so we don't publish as much as non-commercial entities would. And so people's track records will look like there's less papers than somebody sitting next to them who is not working on a project like this.

Participant 19 added: The younger ones are like 'I've got this goal to produce five papers this year and really have to work on something more immediate'.

Moreover, Participant 19 said the requirement of the funding body, the ARC, that the consortia adopt traditional academic metrics such as publications and grants – despite the project's goal of more commercially-oriented outcomes -- made it "quite difficult"

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[118] Well known university ranking systems such as the Times Higher Education World University Rankings, the QS World University Rankings, and the Centre for World University Rankings, incorporate staff publication numbers, citations, and journal influence as major criteria in their evaluation. See https://www.timeshighereducation.com/news/ranking-methodology-2016; http://www.topuniversities.com/university-rankings-articles/world-university-rankings/qs-world-university-rankings-methodology; and http://cwur.org/methodology/.

to change the mix of people and skills as work progressed through various stages. For example, some researchers who Participant 19's group wanted to add to the project did not join. The participant explained why: "Because they thought they were getting no kudos, because, you know, they didn't have the grant on their Curriculum Vitae, officially".

To summarise, all employers need clear methods for evaluating the work of their employees. But without exception, participants in my case study claimed that the performance indicators, that is the metrics, used to assess the quality of their work can be a barrier to innovation. Publication data is also an important metric used to evaluate institutions.

Given the pressure to 'publish or perish', participants said scientists feel compelled to write numerous papers. Because researchers fear losing momentum on their track record and career path, time spent writing papers often comes at the expense of risky but potentially productive science. In regards to the bionic eye initiative, specifically, participants said they felt the traditional academic metrics they were required to apply to the project created roadblocks in terms of attracting and retaining skilled researchers. In essence, participants said the pressure to meet metrics places measurable outcomes ahead of impact, "wheel-cranking" ahead of innovative science.

Isolationism—silos and turfs: "You might think that being science, biology and physics would have the same culture but they don't" (Participant 11)

It is a truism that people enjoy working with others who share their goals and interests. While collaborating with people from different academic backgrounds can trigger new ideas, it is often easier, or useful, to develop a form of isolationism, to remain apart from others for intellectual or logistical reasons. According to participants, academic isolationism generally takes two forms: silos and turfs.

Silos

Silos develop when researchers team-up with like-minded colleagues within in the same discipline. They are informal associations found in many organisations. I use the term to refer to the tendency of groups to work in isolation from others within their institution. In academic culture this tendency to form silos is exacerbated by the long-standing inclination for researchers to work in discrete disciplines such as astronomy or sociology.

Disciplinary silos foster sub-cultures which operate with shared values, common understandings, mutual expectations and patterns of behaviour that separate them from other disciplines. Consequently, silos may impede effective communication, even interaction, between researchers from different disciplines. "There's a language barrier between disciplines," claimed Participant 28:

> So, the way that surgeons and clinicians talk is different to how mathematicians talk. It's different to how engineers talk.

Such language barriers can hinder scientific progress, often unintentionally, when members of different groups seek to collaborate on a multi-disciplinary project such as the bionic eye:

> The language, the sort of discipline language, has been a challenge, and people have had to learn … enough about other people's disciplines to be able to follow along and to understand why things matter…Every time new people come in I'm reminded of that. Every time we have a new person, oh yes, I forget that it takes a while to learn how the other people speak. (Participant 28)

Silos, like strategic collaborations canvassed earlier in this chapter, may increase the likelihood of counter-productive disputes within multi-disciplinary projects. Participant 10 said this was recognised as a possibility in the first stages of the bionic eye initiative:

> One of the things I talked to [name withheld] about, was how do we ensure appropriate collaboration between all the groups. But you know, you've got to be really careful here about these inter-discipline disputes within research communities.

That is the case, the participant stated, because if disputes are not resolved they can become rancorous. People waste time and energy arguing with or about others, or not listening to one another. Several participants said this was a serious problem within the bionic eye initiative, as it required input from disciplines as diverse as ophthalmology and engineering. Members of each discipline saw their field as the most important contributor to the success of their consortia's participation in the bionic eye initiative. For example, Participant 8 said their collaboration was driven by engineers, with "minimal" involvement from clinicians:

> They went at it like engineers. 'Oh well, there are two rocky promontories out there. We're going to build a bridge. The quickest way to do this is between two points and it's going to be so strong it can't fall over'. That was the exact wrong approach. And because of that I think it has been unnecessarily costly.

Participant 23 agreed that engineers found it difficult to listen to the clinicians. It took a "very long, consistent effort from the clinicians" to convince engineers on the team that factors affecting the eventual users' satisfaction are "equally or more important than just the device that you design". A participant with a computing background added that it would be "a great thing" if clinicians – not engineers -- drove more biotechnology research programs:

> It instils that research is useful, rather than, say, a team of engineers at a university developing some technology and then waiting for customers to come. You know, it needs to be driven by need, and I think clinicians are in the best position to drive that. (Participant 16)

Disciplinary silos can intensify the belief that one's discipline is the key contributor to a project's success. They may foster disciplinary exceptionalism. For example, Participant 4 said that during the bionic eye initiative some clinicians behaved as if they were superior to engineers:

> I've lived here for 25 years, and it was my first experience in Australia with elitism. You know it was a very egalitarian society, and all of my research relationships up until that date have been very, very collegial and very productive. And this was really based on, I felt, sort of elitist lines … the engineer subservient to the surgeon, and that's the natural order of things and, therefore, it's not to be questioned.

Individual universities can also be understood as academic sub-cultures. They, like disciplines, have their own norms, and speak their own language. They form institutional silos, and engage in inter-silo rivalry. While not discussed directly by most participants who concentrated on the nature and impact of disciplinary silos, Participant 28 mentioned the consequence of institutional silos point-blank. "I think that the barriers between the different universities and institutes … makes innovation difficult."

Turfs

Turfs emerge when a researcher focusses tightly on a research topic to the exclusion of all but the closest colleagues and their students. It is understandable. As discussed earlier in this chapter, competition for scarce research dollars may trigger defensive behaviour by scientists. Participant 16 noted that one response is the formation of intellectually restrictive "turfs":

> If you have an area or turf that you're the only one, say in Australia, who can work in, you don't want competitors, competition from other research groups. Because having competition means you might have less papers. You might have less of a monopoly on the research in that area. That's bad science, and that's not how science works. So, much faster progress could be made by collaborating and allowing other groups to work with you or to work in that area.

In other words, instead of collaborating widely, participants observed that many researchers deliberately create turfs, pursuing specialist areas within their discipline. They do so to build a competitive advantage by dominating a specific area or topic. And, as Participant 19 noted, they defend their turf from perceived competition:

> There's a lot of mistrust. 'Oh, will my idea be taken by someone else' or 'Will someone start working on my idea so I'm no longer numero uno'. So, there's a lot of protectionism.

Moreover, participants noted that students are encouraged by supervisors to create their own turf, perpetuating the defensive cultural norm. Unfortunately, said Participant 19, continuing along a "narrow" path may well help young researchers build a good publishing track record but not necessarily a creative one.

Regarding turfs, several participants said the tendency of researchers to plough the same intellectual field in order to boost funding and, therefore, publication success, is a significant barrier to innovation. As Participant 26 noted: "They will end up asking the questions that they're best in a position to answer so that they can continue to mine the same thread of funding they've always gotten". The participant added that this self-imposed isolation often produces "answers to questions that nobody really cares about".

Summary: silos and turfs

According to participants, the isolationism of silos and turfs hinders productive collaboration and reduces innovative research. Disciplines build silos comprising silo-specific languages, values, expectations and ways of working. The effectiveness of multi-disciplinary collaboration in projects such as the bionic eye initiative can be hindered without careful management, established to reduce the complications and competition disciplinary silos may pose.

Universities can also develop their own barriers to collaboration. As with disciplinary silos, university silos tend to create stresses when different institutions seek to collaborate. The institutional strains may build on tensions arising over competition for funding and publication success, as covered above in *Funding* and *Metrics*.

Finally, at the Individual level researchers may circle the wagons around their speciality to boost funding and publication success. Their wariness diminishes the exchange of ideas, along with the desire to pursue new, potentially productive lines of investigation.

Interpersonal Factors: "It was not uncommon for me to come across people who had very high opinions of themselves." Participant 10

To borrow from John Donne's 1624 Meditation XVII, "No man [or woman] is an island entire of itself; every [person] is a piece of the continent, a part of the main". And so it is with scientific collaborations, especially those involving many players, disciplines and institutions. Still, each person is also an individual. Each has their own personality, goals, and ability to work with others – or not, as the case may be.

Given the inherent characteristics of the academic culture discussed above – competition for scarce funding, the race for publications and a good track record, and a propensity to work in silos and establish turfs – it is not surprising that personality plays a major role in determining the outcome of collaborative projects. Echoing John Donne, Participant 5 said that is the case because every individual plays an important role:

> It's like a jigsaw puzzle, and each one of those [people] brings various parts of that puzzle and tries to fit them together. Sometimes the fit is not as smooth as one would like because of personalities. Some people are more abrasive than others. Some people are more compliant. And all those aspects are factored in when you are dealing with complex interactions between people on very difficult programs such as the development of the bionic eye.

Numerous participants agreed that is the case, generally, and was the case, specifically, with the bionic eye initiative. The following comments suggest that some personalities were considered especially abrasive by others. Each comment is about a different individual. All comments came from male participants and were about male participants:

> So, he's not the kind of guy that necessarily is going to get on with people. So, I'm being quite frank with you. I came to loathe him. (Participant 8)

> He wasn't a promoter of collaboration. He was more a promoter of antagonism, I think. (Participant 4)

> I'd say about half his problems with the university were probably personality-driven …He didn't get on with a lot of people in the hierarchy at [name withheld]. There were a lot of issues with him, and that really hampered us. (Participant 7)

> I had great difficulties in my communications with [name withheld]. And that became really quite difficult, I have to say. I don't think we need to go further in that. (Participant 27)

As Participant 10, a male, said in the opening quote in this section, strong personalities – big egos – are common in research science. In order to be successful in such a highly competitive environment, individuals need solid egos and firmly held personal agendas and goals. Because they hold their agendas and goals passionately, some researchers fail to recognise that not everyone shares them. This ego-driven approach to science may prove counterproductive in the long term. As Participant 16 said, "I think egos are a barrier". One participant provided an example:

> If people want to work with him, then he's happy to help them out and collaborate, as long as they are working towards his goal. But he's not there to waste time with somebody new starting something different that potentially competes with his goal. (Participant 7)

"Some people just can't, and shouldn't be working together," added Participant 4. The participant said this was noted as a potential problem for what became BVA:

> When the project first started, there was an independent person that was put in place to assess the project that we were putting forward. And the advice that I heard that they had said was that they 'wouldn't touch this project with a 10,000-foot pole because these people are going to kill each other'. <laughs> And I think that was probably pretty accurate.

Participant 26 agreed, saying the "Melbourne versus Sydney groups were never going to see eye-to-eye on anything". Worse, Participant 27 says the animosity occasionally stooped to petty levels:

> There was an instance where the Melbourne guys were asked to do something that would help the Sydney program. They agreed to do so, and then did the opposite. And so I remember sitting in a meeting saying this is just sabotage. If we were in industry, the people involved would be out the door. I mean it was really quite bad. So, what's to be gained from that? … It shows that the level of collaboration was tenuous.

According to Participant 2, part of the problem stems from the fact that, in the case of BVA for example, groups were required to work together by project managers:

> You're in a marriage in some respects. Sometimes you're forced into the marriage and it's less likely to work than if you weren't forced. Sometimes you think the marriage is going to be okay, but it sort of sours. And life's too short to be working with people who you don't really get on with or maybe feel that you don't have a great deal of respect for.

Given such examples, it is not surprising that many participants agreed with Participant 17's comment that, for BVA, while individual teams made progress on their individual projects, there "just wasn't sufficient good will" to produce a successful collaboration overall.

Clearly, effective interpersonal skills are critical to maintaining sound working relations when factors such as personality, ego and personal agendas and goals may hinder a collaborative effort. Unfortunately, there is no guarantee that those in senior positions have such skills. An example of what can happen in the absence of the necessary skills involved two participants. They were called to a meeting by senior administrators:

> Basically, they were taking a very intimidating and I'd almost say harassing approach to us to make us feel that we did not have the support of [name withheld] in our research, in what we were doing. Which basically, subsequently, made me shut down a number of the active projects that we had. (Participant 7)

Participant 8 recalled the same meeting in more detail:

> So [name withheld] and I go into this sort of Star Chamber situation and [name withheld] gets up and immediately attacks [name withheld]. He said, you're just a piddling trainee in my hospital system and you're not allowed to be director of a company'. And then [name withheld] chimes in and says, 'the work you're doing is bullshit and we don't believe it. You're incompetent … We don't want you doing this work'.

The participants' story clearly illustrates how interpersonal factors play an important role in shaping the outcome of a collaboration, whether in a research team or a large consortium such as the bionic eye initiative.[119] These factors, from personality and ego to individual goals and agendas, profoundly influence the daily dynamics and working relationships within a collaboration. And that's critical.

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[119] In Chapter 7, *Findings: Structural Barriers to Innovation*, I discuss the importance to innovation of leadership and of people skilled in working within and between both academe and industry.

"Interpersonal relationships are very important for success," said Participant 23, noting that when they are constructive they help overcome tensions arising from the pressures of an academic career. Participant 11 went further, stating that interpersonal skills are "at least on par with capability and knowledge" within multidisciplinary projects such as the bionic eye initiative.

In other words, science is a human project. Great ideas are created and advanced by people. People make or break a project, from the small to the complex. Their passion, their goals, their personality are critical. Get the mix of people right and ideas soar. Get it wrong and Participant 5's jigsaw puzzle may never be completed. These two quotes from Participant 16 summarise the impact of big personalities on big collaborative research projects: "I think there's no room for egos in good science"; and "I think egos are a barrier".

Summary

I am not a scientist. I am not a direct participant in the academic arm of Australia's innovation system. Unlike Pierre Bourdieu, therefore, I cannot write a self-reflective description of *Homo academicus.* Instead, I am an observer and a listener. This chapter reflects my understanding of *Homo academicus Australis*, as revealed by participants.

Through their eyes it is clear that many elements come together to create Australia's innovation system. An essential component is the nation's research infrastructure. And like a Russian doll, the university sector is embedded within the research infrastructure. There, ideas are created, developed, evaluated, even dismissed. And as with any system established by people for people, universities have developed a set of norms, values and expectations which shape and are shaped by the people working within them. These comprise what I call Australia's academic culture.

In this section I identified key features of Australian academic culture and described their effect on innovation. These features, presented here as themes, emerged from my analysis of participant interviews, and go far to pinpoint barriers to innovation within the academic culture. The themes I discussed are *funding, metrics, isolationism-silos and turfs*, and *interpersonal factors*. They are closely intertwined.

For instance, funding is essential for researchers – *Homo academicus Australis* – and their institutions because they must support their respective activities financially. An important criterion for obtaining funding is the track record of the researcher or university. Publication rates and impact are central to the assessment of both individual and institutional track records.

Researchers, therefore, feel compelled to produce publications to bolster their track record and, thus, boost their chances of obtaining funding. If they are awarded grants and other financial support that feeds back into their track record. Ultimately, their track record is critical to professional respect and career advancement. Similarly, universities receive prestige, financial support and students based upon their cumulative track record.

A consequence of pursuing these circular goals can be a defensive, risk averse culture. Perversely, scientists are rewarded with funding and publications by building and protecting a turf which excludes other researchers – and ideas. Universities with high global rankings may seek to maintain the status quo, while those which are upwardly mobile may reinforce the 'publish or perish' metric for their staff at the risk of creativity.

There are additional pressures to intellectually circle the wagons. One such pressure comes from the silos which develop around individual disciplines, such as engineering or ophthalmology. Silos may unintentionally hinder collaboration because silo members speak their own 'language' and maintain their own values, expectations and norms of behaviour. It may be difficult to understand and work with researchers from different silos.

Interpersonal factors also affect the quality of science and innovation created in academia. Among the most significant of such factors are the personalities and goals of individual researchers and administrators. That is especially so for complex, multidisciplinary projects such as the bionic eye initiative which demand productive collaboration to achieve their aims. If personalities and agendas grate, innovation slows.

Participant 16 pulled together many threads of the academic culture when speaking about egos:

> They [egos] can stymie research, so discourage other researchers from working in their area of turf, I guess. So, protecting an area of research and not allowing other people to be involved in it, that's probably a fairly damning one. So, protecting it by criticising other groups, not collaborating

> with other groups, wanting to keep that area to themselves to publish in. Yeah, I guess there's a lot of pressure to publish and to get grant funding, and if you have a speciality that no one else can work in, a special area, that's an advantage. So, it's maybe a problem with the system in general that discourages collaboration.

Despite these pressures solid science does emerge from Australia's academic culture. But it isn't easy to buck the conservative trend. All too often the result is what Participant 7 called an "an uninspiring academic culture", one that poses a barrier to innovation:

> I mean come on. I used to get depressed going to the university when I was PhD student. I mean just nobody was excited. Nobody was trying to get somewhere. Nobody was trying to achieve anything. It was just very depressing … nobody was innovating … You're not expecting everyone to be innovative, but the vibe wasn't there. The vibe wasn't there.

Participant 7 neatly summarised the barriers raised within the academic culture: "The only way I can describe it is a cultural, cultural problem, okay."

Chapter 7: Culture Clash: The Influence of Industry and Political Cultures

Introduction

This chapter builds on the previous chapter – it too is about culture, but with a focus on clashes between cultures. The participants in my study provided many examples of situations in which people from different cultures within Australia's innovation system bump up against each other in ways that hinder effective collaboration.

The bionic eye initiative comprised more direct involvement from academics than from politicians and people with industry experience. Participants, therefore, commented more extensively about the nature of academic culture. Regardless, they spoke freely about their views of and experience with the political and industrial cultures in the nation's innovation system. They provide important observations into why and how the cultures often clash.

The following two sections, *Uneasy alliance: industry-academic mismatch* and *Political churn*, analyse the influences on innovation of Australia's private industry and political cultures. Many, but not all, of the participants quoted here are academics. When it is relevant to know a participant's background I make that clear.

Uneasy alliance: Industry–academic mismatch

Academics can differ markedly one with another, as discussed in the previous chapter. They nonetheless tend to share a set of values and expectations that have evolved into what I call academic culture. This is not the case when academics and industry people seek to work together. Vast differences separate their two cultures.

> Definitely the distinction between industry and the academic sector [makes innovation difficult]. It's because you're either one or the other. It's very difficult to straddle that successfully. (Participant 28)

What distinguishes academe and industry in this context are differences in norms and incentives operating within each group. These differences may cause conflict when people from the two groups work together. Specifically, then, what are the most disruptive differences when industry and academe try to collaborate? For Participant 26, the answer is as follows:

> It's not true for everybody, but in general academics are incented [sic] by different processes [than industry people]. They are motivated by different things … And if you look at commercial people as well, they're also motivated by different things, and they measure success differently from academics.

The participants in my case study provided insight into what those "different things" are –insight into the nature, dynamics, and implications for innovation of the cultural differences between the academic and industrial worlds. I discuss these cultural differences below in two sub-sections: *The bottom line* and *The view from academe*. I end this section with a brief *Summary.*

The bottom line: "We didn't want to stand there and throw stones at them … but we're not an active participant" (Participant 25)

The statistics are stark. Using 2010-11 data from the Organisation for Economic Co-operation and Development and the Australian Bureau of Statistics, Australia's Chief Scientist reported in 2014 that out of a total of 33 countries, Australia ranks 32nd on business-research collaboration for small to medium enterprises and 33rd for large firms (Chubb, 2014b, p. 10).

As indicated in Chapter 2, there are structural impediments behind the industry sector's poor record in business-research collaboration. Among these are limited financial support for research and the small size of the Australian market. I will cover these and other obstacles to innovation in detail in Chapter 8, *Structural Barriers to Innovation: Politics and funding.* Here, I discuss what my participants took to be the core values underpinning industry's approach to the process of innovation. Most of the quotes in this section are from participants with academic experience. Some have worked in both academia and industry.

At the most general level, people within a commercial enterprise are "focused on the broader goals of the company" (Participant 19). This means that while there can be more than one department within a business, the employees – including research and development staff – hold primary loyalty to the business, not to their immediate department. As such, there is less conflict between individuals and groups within industry than in academe.

This focus is opposite to the situation in academia. There, scientists seem to have stronger bonds with their research group or discipline than to their university. This is reflected in the fact that interviewees spent most of their time talking about interactions and relations with their fellow scientists and program participants. Virtually no one discussed university-wide issues other than metrics and track records.

Within industry, participants believe career advancement is not based as heavily on an individual's track record of personally-oriented accomplishments, as it is for academic researchers. Instead, advancement is based on the employee's contribution, understood as productivity, to the track record of the firm.

In turn, the metrics underpinning a business's track record are far from the academic research world's primary reliance on publications. "In terms of industry, I think the major driver is money," said Participant 16. Money comes primarily from the marketplace and investors, only secondarily from participation in government-funded research projects. The income it generates supports the activities and goals of the company, not those of employees. Money, primarily profit, is *the* measure of a successful private venture.

There is a certain efficiency to this attitude, one not observed in academic culture. Academic project managers, for instance, negotiate complex interpersonal relations differently than do their counterparts in industry. They do so, in large part, because they often do not have institutional authority over project team leaders and their team members whose salaries are paid by the university, not the project. Industry hierarchies are more clearly defined than university hierarchies, and, as a participant with both academic and industry experience stated, the conditions of employment are straightforward:

> You are much more flexible in how you can manage people, and they basically have to do what they're told. It's a fair day's work for a fair day's pay … If we don't bring money through the door, you'll all lose your jobs <laughs> So that's a motivating factor. (Participant 19)

A significant implication of the focus on the bottom line is that, within Australian industry, little room exists for 'blue sky' thinking. Instead, private sector research and development (R&D) is heavily geared towards delivering a pre-determined product or process to the marketplace. Innovation equals "relevance to the market", claimed a participant with both industry and academic experience, noting that "Innovation only occurs when someone writes a cheque out to pay you for something" (Participant 25). That is, the innovation process is advanced by industry primarily in order to make a profit from a new product or service which can be commercialised.

Participant 7 agreed, and stated that is the case because Australian industry is risk-averse. As described in Chapter 2: *Innovation in Australia,* industry has little interest in early and middle stage research. That is especially true when collaborating with academic partners, as opposed to in-house or other industrial partners. Industry is interested primarily in the development (or commercialisation) phase, not the research phase, of R&D.

> Commercial partners are not really that interested in taking, in Australia anyway, in taking research level concepts … all the way through to commercialisation. They're sort of more interested in, okay, once you have a viable product then we will engage in the issues related to commercialisation of the product which includes regulatory authorities … and post-market surveillance, and marketing and pricing. (Participant 7)

Participant 24 also stressed that because Australian industry is "becoming more and more risk-averse", it is increasingly uninterested in collaboration, unless the concept is well along the developmental pipeline:

> I know they get thousands of ideas put to them from emails and personal representations, and so on, to develop this or that or the other products, whether it be a vaccine, a drug, in our area some sort of device or whatever diagnostic. And they have to make business decisions. And one of the things that will really influence them, I think, is how developed that idea is when it comes to them.

That was the case with the bionic eye initiative, according to several participants. This is why Participant 25 said in the quote beginning this section that their organisation "was not an active participant" in the initiative, despite being an official Contributing Research Collaborator on BVA's funding proposal. After looking in "detail" at the market prospects for a bionic eye, the industry-based participant concluded that "if there's a commercial opportunity in this area, I don't know where it is".

This fits with comments from Participants 7 and 26 that a major question determining whether or not industry picks up a biomedical device for commercialisation is the likelihood of receiving government support in the form of rebates on the purchase price. "If it's not going to be rebatable by governments, then it's pretty much a no-go" (Participant 7).

According to Participant 26, however, there would never be enough bionic eye users to justify government rebates, "which means it's probably not likely to ever end up as a real commercial story". The participant, who has industry experience, explained the reasoning behind this conclusion:

> I did a bit of an economics kind of argument … and my conclusion from that was that you'd never be able to fund [development of a bionic eye] with traditional sources of funding because it was like twice the base rate of return [without a rebate]. So, a venture capitalist putting money into something wants to look at opportunities that give them two or three times the amount of money that they've put in, back again. If the prime rate is 6%, then this thing would only return twice the prime rate over a 20-year period, which makes it almost un-investable. It's almost completely un-investable.

While participants with experience in industry-academic collaboration noted the importance of a marketable commodity to industry partners, many bionic eye participants from the academic sector did not see a commercial product as the goal of the initiative. Unlike Participant 27 who viewed the goal of the bionic eye initiative as "real product development", they saw it as an opportunity to do "extra research". For example, as discussed in Chapter 5, Participant 17 claimed that within the BVA there was "really strong opposition to the whole concept of commercialisation".

Clearly, a cultural clash between industry and academics played a role in the way in which BVA, at least, managed their participation in the bionic eye initiative. Combined with information reported in Chapters 2 and 5, my qualitative data suggest this clash hinders effective industry-academic collaboration, more generally.

This difference of world views is detrimental to both sectors of the innovation system. It hinders mutually-beneficial cooperation between them. The wider society also bears a cost. Potentially useful products and processes are not available for sale and use domestically. Neither can they contribute to the overall economy through export to foreign markets. Hence, Participant 16's observation that for Australia to boost its rate of successful innovation there "needs to be interest from industry in working with scientists". Participant 22 went further:

> I think we've got to get more PhDs working in industry. Industry shouldn't be scared of PhDs. They shouldn't be worried that PhDs are unproductive.

In other words, the industry sector's focus on the bottom line both creates and reinforces a reluctance to collaborate with research academics. In the following section I discuss the equal and opposite view from academe.

The view from academe: "There's a tendency for research to look at businesspeople with thinly-disguised disdain. This attitude gets it nowhere" (Participant 31)

Headquartered in Seattle, Washington, PayScale Inc. describes itself as "the leader in modern compensation software". According to the group's estimates, the average salary for a research scientist in Australia is A$77,852 per year. "Most people with this job move on to other positions after 20 years in this career," the site advises.[120] Without details of PayScale's methodology, it is impossible to gauge how accurate the figure is. Nor does it break down the averages for publicly funded scientists and those working within industry. Still, the estimate does underscore Participant 21's claim that academic research is not the royal road to riches:

> I'm not doing this because I can make money here. I'm doing this because I'm interested in the inquiry and the science and the collaboration, and the engagement with the students. And if I can do that with an industry partner that's great, and maybe that will make some of what we do more relevant, and maybe it won't.

The contrast with industry goals and metrics is clear. Given this difference, it is understandable that the prospect of distrust and conflict between the two cultures is real. Participant 7's view of industry is a case in point:

> The role of the commercial partner is to do what commercial partners do, which is if they can leverage university research and have their finger in the pie to potentially grab something useful, they're there and ready to go. But that's pretty much all you can expect from the commercial partner, obviously. They sort of know that a lot of this university stuff is a waste of time, but occasionally there might be something interesting that they want to be able to do.

This antipathy towards industry reveals that the 'us-them' perspective covered in the previous chapter extends beyond academic culture. The intensity of out-group aversion ripples away from the core research scientist or team. Given that many university scientists have limited experience working beyond academe, it is understandable that

[120] See http://www. payscale.com/research/AU/Job=Research_Scientist/Salary

when they do collaborate with industry they may, as Participant 17 noted, seek to control aspects of their professional circumstances such as the scope and specifics of a research project. This runs counter to the top-down control widespread in the private sector.

The ‘us-them’ tendency can be acute if academic and industry collaborators come together primarily for funding purposes, as was the case with the bionic eye initiative. For example, Participant 17 described the attitude of university researchers towards, not a commercial organisation itself, but an industry-oriented research institute with which they partnered under the bionic eye initiative.

> There’s still within the university an academic culture which wants to control the research of the institute through university-based academic departments, rather than to identify with the institute and its potential industry connections.

While there are understandable reasons for this attitude, given the metrics applied to university career advancement, it can prove a stumbling block to productive collaboration, much as it does inside the university system. Without the input of industry expertise, for instance, there is less likelihood that project managers and researchers will make fully informed decisions about the commercial potential – or otherwise -- of various lines of research. As Participant 21 says below, academic scientists often have little insight into which research projects have commercial potential – and are, therefore, likely to be of interest of industry – and which do not:

> A lot of time the industry conversation [amongst academic scientists] is, well, they weren’t interested in my project. But often, as I said, it wasn’t very interesting. <laughs>

In the case of the bionic eye initiative, it is arguable that had industry participants been more intimately involved in the earliest formulation of the initiative itself, or in the preparation of funding applications from consortia responding to the opportunity, one or more prototypes might have been ready to move from proof-of-principle to commercial development at the end of the 5-year funding period.

But as outlined in Chapter 5, early-stage discussions involving academia and industry were never likely. The initiative itself was largely the result of lobbying within the university sector and then at the political level. As Participant 25 noted above, their commercial enterprise was “not an active participant” in BVA, despite being an official partner.

Not only is the university sector often a reluctant partner with industry, industry experience is not widely welcomed. After establishing and running a successful start-up venture for roughly a decade, Participant 19 was discouraged from returning to academic research:

> Nobody wanted to know any of this experience of how do you take an idea and two people working on it, coding software with a computer sitting on the ironing board, that sort of thing, printing out labels, how did you go from that stage and turn it into this big business supporting lots of innovation and rollouts of systems … did anyone want to know? No, nobody wanted to know at all. They wouldn’t even give me a lab when I came here. It’s like ‘you’ve got to get a grant first’. <laughs>

According to Participant 19, the central importance in the university system of maintaining a solid publishing and funding record discourages scientists from moving between academia and industry. “People said it’s like ‘oh you haven’t done anything for ten years’”. I discuss this matter further in the next chapter, *Structural Barriers to Innovation.*

Additionally, most young researchers do not even think of working outside of academia, unlike their cohort in Boston or Silicon Valley, claimed Participant 23:

> A lot of [US] researchers go in thinking they are going to do their start-up company and make their millions. So that’s their, often their thought process is that that’s what they’re going to do. Whereas we come into research thinking that’s what we are going to do for our career.

Summary: Uneasy Alliance

My interview data suggest that many members of the academic and industry sectors have little, if any, experience working together. The result is that they do not understand or share the other sector’s values, common understandings, mutual expectations and patterns of behaviour. Most critically, the sectors have different goals, and they evaluate the performance of their people in different ways. It is not surprising that distrust, even animosity, between people in industry and academe is common. Productive collaboration is, of course, possible. But as global collaboration statistics reveal, success is more honoured in the breach than in the practice.

Political churn

Political culture: "Politics is about who gets what, when and why" (Participant 10)

Politicians and people working directly with them choose their careers for many reasons. Their sense of job satisfaction is, similarly, multi-varied and personal. But once they are on their chosen path, their performance will be evaluated by others.

As discussed in Chapters 6 and 7, in academe and industry, major criteria for assessing performance are, respectively, publications and profits. For those working in the political sector, the fundamental metric is votes. Politicians seek to get elected and stay elected, said a participant with political experience. Another participant added that if they lose office they cannot pursue their political goals, and their advisers and support staff are out of a job, as well:

> You've got to win. You've got to win. Politics is about winning too. You know this notion. I mean you don't want to be too romantic about these things. I mean it makes a difference. The government of this country makes a difference … You change the government, you change society. (Participant 10)

And opportunities to change the government come frequently. Under the Australian Constitution, the Commonwealth House of Representatives, the dominant policy-making chamber, remains no more than three years after it first meets, but may be dissolved earlier. This is not much time for a party to hold the levers of power. In reality, it's even less. The 3-year cycle is effectively an 18-month cycle:

> That's what it is. You spend all your time getting elected, then you've got one-and-a-half years to put some stuff in play, then you start the election cycle again. (Participant 9)

Does this pace have an impact on innovation? Participant 24's answer expressed the sentiment of many participants:

> I think so, yeah. I think everyone would say that. I think it should be a bit longer than three years, but having said all that, there's a lot of politics on both sides.

The political cycle poses significant structural barriers to innovation which I discuss in the next chapter. But as Participant 24 suggested, the political cycle also shapes the “politics” -- the behaviours, values, goals and expectations – which politicians and their colleagues bring to their job, either as members of a governing or opposition party.[121]

Each political party is passionate about their view of what is best for the country. As Participant 11 said, “Governments are elected with agendas they would like to prosecute”. Doing so, however, is far from straightforward. Australian political culture is notoriously partisan, making it difficult for a governing party to implement their goals, according to a participant who has worked closely with politicians, their advisers and government employees:

> There are some areas of public policy [about] which you say that there is broad acknowledgement [consensus] in the political culture. But most of the big questions are highly contested [by politicians].

In particular, science and innovation policy are always politically contentious. As discussed in Chapter 2, such policy is ad hoc, changing from government to government. The policy environment is made more uncertain because, as Participant 11 said, innovation is “not something that a typical minister would have at the top of their stack of papers”.

This is the case primarily because politicians bring different skills to their job than do academics or people in science-based industry. Few Australian politicians have any direct or indirect experience with science or research, from either an academic or industry perspective. They make important decisions about policies affecting areas about which they have limited first-hand understanding.

> I really don’t think most of these people [politicians & their advisors] get it because they are either economists or lawyers, for example. And so there’s a lot of disciplines that are involved in the bureaucracy and in politics that don’t necessarily have a background or much of an understanding at all about innovation or even, I’d say, business or how society creates value. (Participant 25)

Another reason to shuffle innovation towards the bottom of the ministerial pile is the fact that science and innovation are seldom high-priority issues with the general public. Most Australians are not scientists, do not work in scientific businesses, or know anyone who is or does. The result is limited pressure from voters for policy action

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[121] There are a handful of small party and independent parliamentarians within each Parliament. They may influence the outcomes of some government decisions, but do not control the levers of power which affect the national innovation system.

affecting science and innovation, except where research overlaps with areas of some public concern, for instance renewable energy or aspects of communications technology such as the National Broadband Network.

Collectively, scientists, themselves, do not form a significant pressure group with a block of votes to offer in return for support delivered to innovation-oriented research and development. Bodies like the Australian Research Council (ARC), National Health and Medical Research Council (NHMRC) and Australian Academy of Science (AAS), for instance, do not have the clout of big business and lobby groups representing segments of the population with significant economic and political influence. Participant 9 pointed to the "power of the extraction industries":

> [It's] an incredibly powerful lobby, incredibly powerful. And I shouldn't just single out the extraction industries. The Australian economy allows political expediency.

Still, politicians -- especially those heading ministries covering science, medicine, technology and innovation – know they have what Participant 16 called an "important role in terms of funding research and also guiding research at the policy level".

To help them in the process, ministers have advisers on their personal staff. Distinct from departmental civil servants, the Office of the Chief Scientist, or the heads of bodies such as the ARC and NHMRC, advisers play a political role and are selected and hired by the minister. According to Participant 9, advisers are "the minister's eyes and ears," offering "guidance" on issues in specialist areas, from innovation and intellectual property to science funding and venture capital. "I have to admit that there's so many things I can't remember now," the participant said, recalling all the areas of responsibility held when in an advisory role.

Advisers are also the on the front line, dealing with groups and individuals wishing to persuade a minister to provide funding or other support for their activities. Many such lobbyists represent the academic community:

> Universities pitch research projects to government all the time outside the standard grants rounds. Few are successful, but we keep pitching … Our role finishes when the idea is evaluated within government process, where it is usually subject to strict confidentiality. If successful, we might get a call from the minister announcing the decision. More often we get a letter from an official explaining that our proposal was not successful on this occasion. (Participant 12)

When reflecting on the lobbying surrounding the bionic eye initiative, Participant 6 put it succinctly:

> You can't get past that politics is a part of life, and we all deal with that. And clearly, you know, the medical researchers are as good at playing the politicians as anyone.

In fact, medical researchers have been highly successful in obtaining funding. Everyone has a body, and is concerned about their health and that of their family and friends – even politicians. To illustrate, the conservative government of Prime Minister Tony Abbott announced a $20 billion Medical Research Future Fund in May 2014,[122] while simultaneously cutting back scientific research.

Regardless, even with an established connection to a minister or even the prime minister – what Participant 8 calls the "mates' network" – getting a hearing at the political level can be difficult, said Participant 11:

> It's an incredible issue, is to get their time. And, as I say, even their advisers don't have time because the advisers are on the lookout for what's going to bite the minister the next day, say, a headline or something. Everybody is working on that short [3-year] time scale, at the same time they do this juggling of a very heavy workload.

Given the range of topics and duties performed by advisers and the attention ministers must pay to party, parliamentary and public issues, it is not surprising that, as Participant 9 said, everything from setting policy and meeting constituents is "rushed".

According to several participants, even when researchers finally obtain a meeting with a politician and/or their adviser, they often fail to maximise the opportunity by confusing approaches suited to academic culture with those suited to political culture. Too often university researchers believe their enthusiasm, alone, for a project or line of research will convince politicians to support their cause. They are not strategic. "Good science" is not enough, commented Participant 2:

> You've got to have a good story. You've got to have shown that, yeah, there is future benefit in that. But you've got to be able to get it in front of the politicians at the right time, as well.

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[122] See the 2014/15 Budget Paper #2, Expense Measures http://www.budget.gov.au/2014-15/content/bp2/html/bp2_expense-12.htm and http://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/pubs/rp/BudgetReview201415/Science

According to Participant 20, while academics know this intellectually, once they've finally get time with a minister, they often "misread" the impact of the meeting:

> The hardest message I find to get through to the scientific community is that a one-off event doesn't change threshold thinking … I've seen people come out of the minister's office and say, 'Oh, that was a great meeting', and you know absolutely for a fact the minister is thinking about what he's having for dinner that night or who is next on his agenda. You know when they seriously change that minister's thinking is when they've been in there five times over 12 months to constantly push the line that this is important for this reason.

Politicians are quite aware that academic lobbyists are convinced their ideas are absolutely deserving of government support. As a result, they are, as a political participant noted, "circumspect" about the claims made by advocates:

> As a general policy position, I'm not there to pick which particular genius is more worthy than the others.

Instead, politicians leave decisions about the evaluation of applications for research projects such as the bionic eye to formally constituted funding bodies like the ARC and NHMRC. But when it comes to establishing projects, long or short-term, politicians rely on various sources of counsel, from advisers, the heads of funding bodies and the Chief Scientist to their political colleagues and people within their informal networks. This fact is something academics often fail to recognise, said Participant 20:

> And there's no point going to a politician and saying 'I've got a great deal for you, here it is, and I expect you to embrace it because I'm telling you'. Even if it's good, they'll talk to other people. Well, they'll be at a rubber chicken dinner somewhere and say 'oh somebody came up with this great idea what do you think of that?' 'I think it's absolutely crap'. They say 'oh yeah right-o thanks' and the temperature drops again.

One of the key goals of all ministers is to publicise their work, letting constituents know they are fulfilling the agenda for which they were elected. This is an "intensely political process", one that is necessary "to get things done" said Participant 10:

> You can't get around the fact that unless the public is engaged, that's what I mean by 'politics', it's not just about the work of government. It's about developing a political agenda to engage the public.

Participant 6 added that "Governments like to have things to show off". This is an important activity they hope will translate into votes. The number of votes garnered at an election is, as noted earlier in this section, the political equivalent of academic publications and citations. Consequently, ministerial staff are pressed to identify frequent newsworthy 'announceables' which can be handed to the media as press releases. These often accompany speeches or press conferences such as Prime Minister Kevin Rudd's 2008 announcement that the government would fund the development of a bionic eye.[123]

This pressure to publicise holds significant implications for the development of innovation policy which I discuss in the following chapter. Meanwhile, Participant 11 summarised the kind of announceables preferred by politicians:

> What politicians want is something that they can feel proud of that they've funded. Something that is at the cutting edge, that is seen as Australian, and that, you know, even if it doesn't deliver on the promise, at least won't end in tears.

One participant, a politician, described what that means in practice:

> I had to make choices. I could either have little tiny projects which no one would take any notice of, and maybe get them permanent. But they were of such small consequence that people would say, 'oh it doesn't really matter' [if they were not funded].

In other words, politicians favour high-profile, significant-looking projects. They also tend to support short-term projects because more of these can be announced to the public for the same amount of money as one or two large projects. I will discuss this topic in further detail in Chapter 8.

All up, politicians and their colleagues operate within their own culture, distinct from the cultures of academe and industry, reported participants with and without political experience. Politicians seek to get elected to accomplish the goals they believe are best for the nation. Once in office, a government has three years or less to make its mark before another election must be called. This makes long-term planning and governance difficult. The sense of urgency is heightened by the reality that they must begin working towards the next election after about 18 months in office.

While in office, as several participants noted, ministers and their staff are very busy managing the daily tasks of running the country, while working with political

[123] See Chapter 3, *The Bionic Eye.*

colleagues, maintaining fruitful relations with supporters and informing the public of the 'success' of their work. In portfolios dealing with science, technology and medical research, ministers and their staff meet with numerous academics and university officials, all seeking support.

Unfortunately, the people they meet, especially researchers, often have limited understanding of the day-to-day realities of political life. The consequence can be outcomes that are not always in the best interests of effective collaboration, policy formulation and support for science and innovation.

Summary

In this and the previous chapter, I discuss "culture", how it is defined and debated within anthropology. I also make clear that I use the term, not in a theoretical sense, but as a way to refer to the shared values, common understandings, mutual expectations and patterns of behaviour of a group.

While this definition observes the commonalities within a group, it does not dismiss the diversity within the group. It is, therefore, a useful tool for comparing, contrasting and discussing data obtained from participants working in different components – cultures -- of Australia's innovation system.

Using this approach and my interview data, I have identified and characterised the main cultural groups within Australia's innovation system -- the academic, industry and political cultures – and analysed the complex dynamics operating within the academic culture. In this chapter my findings report on the often counterproductive clashes between these cultures when they rub professional shoulders.

At the broadest level, my participant data suggest that the most significant cultural barrier to innovation is the fact that academic, industry and political participants in the national innovation system do not see eye to eye. They do not share the same goals, ways of operating and measures by which they are rewarded for their professional effort. The differences come into particularly sharp focus when academe and industry collaborate -- or clash.

Still, academic researchers and science-based business people understand the fundamental processes of research and development. Participants, however, claimed that politicians and their advisers are distant from the realities of such activity, seldom having experience or expertise in either arena. This situation can make effective communication difficult, especially between academics and time-poor politicians. This is an important barrier to innovation, one that has an impact on the quality of science and innovation policy and, ultimately, the productivity of the innovation system.

Finally, the nature and impact of cultural values and behaviour identified by participants have practical consequences which affect the structure of Australia's innovation system, as well as its effectiveness. I will discuss these consequences in more detail in the next two chapters.

Chapter 8: Structural Barriers: Politics and Funding

Introduction

Innovation does not happen in isolation. Even the near-mythical lone inventor must interact with others to bring their product to market. That is so because innovation is a complex process involving numerous people and, in most instances, numerous organisations.[124] Over time, the people and organisations arrange themselves into a system. As discussed in Chapter 2, Australia's innovation system developed in an ad hoc manner as the original colonies evolved from their early role as providers to the 'Mother Country' of mineral and agricultural resources to an independent nation, increasingly linked to the global economy.

The resulting system of innovation consists of three main components: the political sector, federally-funded universities and organisations, and private industry. The nature of and interactions between these components shaped – and continues to shape -- the system, or framework, in which Australia's scientific innovation occurs.

Important elements within today's system are subject to intermittent alterations, primarily due to changes at the political level. These chops-and-changes unintentionally erect what I call structural barriers to the innovation process, that is to the creation and development of ideas, as well as to their translation into new products or processes.

Such structural barriers, then, emerge from the nature of the system itself. Others result from the interpersonal dynamics within components of the system discussed in Chapters 6 and 7. Taken together, these barriers reflect the fact that structure affects culture, and culture affects structure.

Like the preceding two chapters, this chapter and the one following present an analysis of themes derived from my interview data. These chapters evaluate structural barriers within Australia's innovation system. As will be seen, many barriers are closely intertwined. The data could be presented in several ways. To manage this complexity, I have created headings which I believe best represent the over-arching structural barriers

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[124] See Chapter 1, *The Concept of Innovation* for a discussion of the concept of innovation used in this thesis.

to innovation identified by participants, and I present them over two chapters. Aspects of some themes are presented under more than one heading.

I begin with a discussion of *Policy and politics* and *Funding* in this chapter, followed by a Summary. In Chapter 9, I consider *The tyranny of distance* and *The talent pool*, before concluding with an analysis of the so-called *Valley of death*, from which promising products and processes seldom emerge.

Policy and politics: "Political leaders here are just dominated by short-term politics" (Participant 3)

Imagine running a business with most of the staff on a 3-year contract, from the Chief Executive Officer on down. The contracts may or may not be renewed, depending upon how the business owners perceive the performance of the team. That, in essence, is how Australia's political system operates. Voters elect a government and hand them control of the levers of power with the proviso that they may, or may not, re-elect them at the next election.

As discussed in the previous chapter and in Chapter 2, under the Australian Constitution the Commonwealth House of Representatives is the dominant policy-making chamber. It remains no more than three years after it first meets, but may be dissolved earlier. This is not much time for a government to make its mark. In reality, the time is even less.

Governments begin working towards the next election after about 18 months in office. They want to show the public that they are successfully governing, that the previous government was not and that they are worth re-electing. There are several strategies all governments use to compensate for the reality of a 3-year political cycle, and nearly all participants agree with Participant 22 that together these strategies pose a "hinderance" to innovation. "[Politicians] knock over projects that you thought were established," Participant 10 said. Participant 11 agreed:

> A new government comes in and, quite frankly, most of the time what they like to do is sweep away the old policies and introduce some new ones. And so I think it [the 3-year cycle] can have a detrimental effect.

Several participants noted that even when programs are continued, incoming governments rarely resist interfering. As a consequence, many promising projects are left unfunded or unfinished, unless other sources of funds are found. This suggests another implication of what Participant 3 above called "short-term politics. "We get out too early," said Participant 21, who then expanded on the point:

> Look, I think the issue with government policy and innovation is continuity. I don't think we give enough of various things an opportunity to work before we decide that we've got a problem and we need to do something else … There are some unbelievably good outcomes from the Cooperative Research Centre[125] programs, but just when it kind of gets into a groove, the government changes and they call a review.

The 3-year political cycle has other deleterious effects on innovation. It hinders the ability of the Commonwealth to plan long-term for national strategies. It also makes long-term planning difficult for federally-funded research agencies and universities, as it also does for the private sector. Day-to-day governance becomes difficult for research and industry managers because they are forced to handle frequent changes in policies, programs and regulations. Changes to funding volumes and priorities are particularly disruptive because many projects cannot be completed within the two to four-year funding envelopes preferred by politicians. I discuss this consequence of the political cycle in more depth in the next section of this chapter.

New governments are also unlikely to enter office with a deep understanding of the nature and dynamics of science and innovation. It takes time to understand how the complex process works. As Participant 25 said:

> [Bureaucrats and politicians] don't necessarily have a background or much of an understanding at all about innovation or even, I'd say, business or how society works.

This situation is worsened by the fact that, as Participant 11 stated, there is little "cross-talk" between ministries with portfolios, or areas of responsibility, that contain topics that link to science and innovation:

> So, water policy was over here, and energy policy was over here, and climate change policy was over there, but in fact these all interact through physical science in very profound ways.

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[125] Established in 1990, the CRC Programme is a competitive grant programme that supports industry-led and outcome-focused collaborative research partnerships between industry, researchers and the community. http://www.industry.gov.au/industry/IndustryInitiatives/IndustryResearchCollaboration/CRC/Pages/default.aspx

And it is not just policy that is profoundly affected. As policy expert Roy Green wrote in 2016, "The $9.7 billion annual funding for research and innovation is spread across 13 government portfolios and 150 budget line items, hampering coherence and effectiveness" (Green, 2016). Aggravating the situation is the fact that, like policies and programs, portfolio responsibilities change when the government changes. Governments may even shuffle, or reshuffle, their own ministries and portfolio responsibilities while in office.

Compounding the problems posed by shifting and poorly integrated portfolios, interviewees say components of new policies created under portfolio auspices may be poorly designed. This is not just due to a shortage of politicians, advisors and departmental officers who understand how science works, but because they may lack a corporate history of the area. Participant 21 illustrated this point with a personal experience. The anecdote reflects the fact that because of these knowledge and experiential deficiencies new minsters and staff often suggest ideas already tried and proven largely unsuccessful:

> So, I'm at a meeting where someone says, 'I think we need to …' and one of the government officials who is just new to the field goes, 'What if we weighted the industry funding a bit more heavily. Do you think that would make a difference to this problem?' [laughs] And I went … 'I've got to emigrate because I'm so over this conversation.' So yeah, it's frustrating.

Another barrier to effective innovation policy stemming from the political cycle is that politicians and their teams seek to keep constituents such as industry and universities onside during their term in office. As discussed in Chapters 2 and 7, politicians also want their constituents' support at the next election. Industry is seen as a source of campaign donations, while the, albeit smaller, university sector promises votes, rather than funds, to the party which seems to best represent their interests.

When politicians adjust programs and policies to suit important lobbyists, this may contribute to what observers call 'decision-making on the run' -- making decisions regarding policies or projects without spending sufficient time to build an evidence base for them. That, in turn, interferes with sound policy development and project decisions by governments.

> While ever we're having short-term kneejerk responses to industry priorities, you'll have short-term objectives around your research and innovation effort. (Participant 21)

As a result of such dynamics, numerous participants expressed dissatisfaction with what they see as a tendency by political leaders to give into pressure by lobbyists or the dictates of the political process. Some couched their beliefs indirectly, using phrases such as a "[lack of] courageous decision making" and "kneejerk responses". Others, as quoted in Chapter 7, were more direct and described the phenomenon as "political expediency", a "mates' network", an "intensely political process", and the like. Participant 18 stated it bluntly:

> So, what can I say. Political will is lacking to make a bold statement. Nobody thinks they're a leader. They think about how they will be re-elected. We live in a very selfish society.

Overall, the picture painted by participants is one in which political leaders and their team are constrained by the election cycle. They want to get elected and stay elected. When governments gain office, participants say they tend to dump policies and projects established by their predecessors, or interfere with activities of established initiatives such as the CRC program. They may also lack expertise and government 'corporate' history. The meddling disrupts the process of innovation which requires time and continuity.

Adding to the tight timeframe produced by the 3-year political cycle, efforts by politicians to appeal to voters and to maintain the support of critical constituents also encourage short-term thinking about policy, participants argued. As a consequence, science and innovation operate in an ever-changing policy environment. Interviewees see this aspect of the innovation system as a significant barrier to innovation.

Funding: "We don't have enough money" (Participant 3)

Participant 3, above, is not alone in the complaint that there is not enough money to drive an efficient innovation system in Australia.[126] Many participants also agree with the claim by the participant, who is not a scientist, that while Australia is "certainly capital investment poor", it is "brain strong".[127] They say insufficient investment hinders the country's capacity to build on the quality of its research. "Overall, the level

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[126] The issues discussed under this subheading are about the overall scarcity of funding as a structural barrier to innovation, and differ from the issues discussed under the funding heading in chapter 6, where the focus was on the way funding systems influence academic culture.

[127] See Chapter 2 for a detailed look at the quality of Australian research as measured on a variety of internationally accepted criteria.

of funding is holding us back,” Participant 24 stated. Other participants echoed this sentiment, including Participant 5: “The barriers [to innovation] are always money”.

Underfunding was one of the most frequently cited barriers to innovation raised by interviewees in my case study. In this section I explore two sub-themes identified by participants as primary causes of what they see as the systemic underfunding of research and development (R&D).[128] These are *The political dimension* driving government funding decisions and the organisation and management of *The funding bodies*, primarily the Australian Research Council (ARC) and the National Health & Medical Research Council (NHMR).

I put these two sub-themes into a wider context beginning with *Overview*. It presents data revealing Australia’s comparative levels of Gross Domestic Expenditure on R&D (GERD) and Business Expenditure on R&D (BERD), as well as insufficient venture capital to refine prototype technology and commercialise it. In the final section of the chapter, *Funding the bionic eye initiative,* I discuss participants’ perceptions of how the funding allocated to the project, as well as the mechanism by which it was funded and managed, imposed barriers on the eventual success of the scheme.

Overview

The complaint noted at the top of this section, “We don’t have enough money”, is not just a belief held by researchers, many of whom are convinced their personal projects are underfunded. The same sentiment was shared by others I interviewed who were not research scientists and so did not depend on research funding for their own career security.

For instance, to quote participant 9, who like Participant 3, is not a research scientist: “There wasn’t enough in any of the buckets to meet their needs”. Others add that, judged against comparable nations, Australia fares poorly in overall funding from both government and private sources.

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[128] I follow the OECD definition of R&D as basic research, applied research, and experimental development. It does not include taking experimental developments, or prototypes, through to commercialisation, a step in the innovation process known as translation.

Participant 11 summarised the situation:

> And so you look at comparisons with the OECD [Organisation for Economic Cooperation and Development], government spending could be a larger percentage of GDP (Gross Domestic Product) compared with many of our OECD partners … But the area that Australian really stands out is extremely low BERDS, which is Business Expenditure on R&D. I mean, I think we're right at the OECD bottom. And so that is the thing that really stands out, that in Australia, compared to countries that we would compare ourselves with, businesses are not investing in R&D … So, I think this is quite telling.

Participant 11 is correct. While Australia's BERD is a serious problem, its GERD is also an issue. Using the most recent comparable data available from the OECD, the World Economic Forum concluded that in 2013[129] Australia fell below the OECD average of 2.40% of GERD. This includes countries and regions to which innovation experts regularly compare Australia: Scandinavia, the US, and Germany, along with Israel and South Korea. Australia's GERD did, however, exceed that of the UK.[130]

According to the forum's 2015 assessment, reported by Paul Muggeridge, Israel and South Korea were the "biggest spenders" in 2013 on R&D, at 4.21% and 4.15% of GDP, respectively. Of the 42 nations reviewed by the forum, Chile spent the least on R&D, 0.35% of GDP. In the overall rankings, Australia was number 16, spending 2.13% of GDP, right below France at 2.23% of GDP and just above Singapore which spent 2.02% of its GDP on R&D (Muggeridge, 2015).

Part of the reason that Australia funds R&D below the OECD average is that, as Participant 11 pointed out, the private sector contributes little compared to that sector's contribution in other comparable nations.[131] As with GERD contributions presented above, the OECD concluded that Israel and South Korea were the leaders in BERD. Again, Australia performed less well than comparable nations in Scandinavia and the US, although Australia's BERD did exceed that of Germany and the UK.

Why is this the case? According to a 2009 government document entitled *Powering Ideas: An Innovation Agenda for the 21st Century*, one reason is scale. Australia has a

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[129] The most recent World Economic Forum assessment available at the time of writing.

[130] See http://www.oecd.org/innovation/inno/researchanddevelopmentstatisticsrds.htm

[131] See Chapter 7, *Culture Clash,* for interviewees' perception of industry's reluctance to invest in R&D.

high proportion of small and medium-sized enterprises (SMEs), and they are less likely to engage in the innovation process than large ones. "The company structure in this country is very small," Participant 10 said. Scale also plays a role added another participant:

> Industry is risk averse, and they're risk averse because we don't have the magnitude. It's a question of critical mass. I think critical mass is the biggest problem. (Participant 27)

Participant 10 summarised the situation: "The private sector is not big on investment".

But as participants from across the innovation system state, the area where Australian business investment falls particularly short is in venture capital investment.[132]

> There's not a really big pool of risk capital. The traditional risk capital that can be like angel investors who can say … if it works great. If it doesn't, oh well, I've got other capital elsewhere. It's that kind of fundamental risk capital that is very, very thin on the ground. (Participant 9)

Because the Commonwealth does not generally support commercialisation, there is, therefore, a shortage of funds for moving experimental developments from the laboratory to the marketplace. And that kind of "risk capital" is "what you need" to do so, stated Participant 9.

According to the interviewee, it's not just venture capital firms that shy away from post-R&D investment. Even national superannuation funds, which hold large amounts of investment capital, contribute little, especially to early-stage commercialisation.

> And it's a real shame that an economy that has so much available capital through our superannuation pension fund, that the contribution from that sector to innovation is so small. And it is based on really strong evidence that the return profile [profit] is not strong enough, therefore, until the return profile gets better they are going to not increase their funding allocation. It's a Catch-22 thing. (Participant 9)

Participant 23 added that philanthropic groups and individuals also invest little, especially when compared to the US. Australia has not developed a strong philanthropic

[132] I use the following definition of "venture capital", which includes three general types of capital: seed capital, for ideas that have not yet come to market; early-stage capital, for companies in their first or second stages of existence; and expansion-stage financing, for companies that need to grow beyond a certain point to become truly successful. Venture capital can also help a company merge with or acquire other companies. See http://www.investinganswers.com/financial-dictionary/businesses-corporations/venture-capital-870

culture, generally, let alone one targeting science innovation. It is "something that's not … well developed," the participant observed.

Many interviewees agreed that Australia does not have Participant 3's the "wealth of capital" available in countries with a strong innovation record, and made a number of similar observations:

> Researchers in Australia face the additional challenges associated with the limited venture capital options available in Australia as compared with the US. (Participant 13)

> The money is not in Australia. It's difficult to get angel or venture capital type money for hare-brained [unconventional] schemes in Australia. It's a lot easier in America. (Participant 15)

> Compared with other developed countries, the amount of investment that we do is poor. The industry investment is equally as poor…I've just come back from Korea, and looking at some of the ways their industries invest is just phenomenal, and you just see the progress it's made. (Participant 2)

The result, said Participant 28, is that "there's not a culture of investment in innovation in this country". Or as Participant 2 explained, "It's a mindset" Australians lack.

According to Participant 18, there is another reason why investors are reluctant to go beyond the R&D phase of the innovation process and "take the next step" to commercialisation. It is "expensive". And it really is risky. Many SMEs go broke:

> One of the greatest sadness, I'll put it that way, is that the historical legacy of prior commercialisation failures has really limited actors in the innovation environment's desire for risk. (Participant 9)

I will discuss the gap between R&D and later stages of the innovation process in further detail in the next chapter in the section *The valley of death.*

Political dimension

Given that the Commonwealth provides the bulk of funding for R&D conducted in Australian universities and national research organisations, it sets the overall priorities. "It's a political decision," to quote Participant 7. Participant 28 agreed: "Obviously, politicians and politics get to decide what they think is worth spending the money on".

In chapter 7 and above I analysed fundamental barriers to innovation created by the federal political system. In this sub-section I discuss, specifically, how the political system affects R&D funding for universities and national research organisations in ways that may create further barriers to innovation.

Key areas affected by politics include support for funding bodies like the ARC and the NHMRC. Political decisions also affect the continuity, or otherwise, of funding schemes, along with the duration of funding available for R&D projects supported through ARC and NHMRC granting schemes. Each of these areas of involvement by politicians has the potential to hamper R&D planning and implementation by institutions and research groups supported by the funding bodies.

I begin with support for the funding bodies. Once a government's overall funding priorities have been established, as noted above by Participants 7 and 28, ministers negotiate for their portion of the annual Commonwealth budget. This, of course, includes those handling the science and innovation portfolio or portfolios, however organised or named.[133] Ministers then determine how their allotted funding will be distributed to the various programs and schemes under their responsibility:

> And they will be advised by people who are proponents for every area, that [the government] should support their area. So, it does mean some courageous decision-making. (Participant 20)

"Courageous" because, as I discussed earlier in this chapter and in Chapter 7, ministers have many masters to please: the general public, private industry, and university officials and sometimes scientists themselves. This may affect their decisions. The bionic eye initiative, itself, is a case in point. As described in Chapter 5, it appears to have been largely the product of discussions between Prime Minister Kevin Rudd and the Vice-Chancellor of Melbourne University, Glyn Davis.

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[133] As discussed earlier in this chapter, when governments change hands or ministers within a government are given new responsibilities by the Prime Minister, portfolios are shuffled and departments renamed. For instance, in the current conservative government Arthur Sinodinos is Minister for Industry, Innovation and Science. His immediate predecessor was Greg Hunt. He took over from Ian Macfarlane, Minister for Industry and Science. Macfarlane was handed the science portfolio after it had been left vacant for a year. Science has been partnered with diverse portfolios, from tourism and technology to resources. The first science portfolio was established in 1994 under the Labor government of Prime Minister Paul Keating. The first innovation portfolio was created in 2007 by incoming Labor Prime Minister Kevin Rudd.

Additionally, ministers may intervene even after money is allotted to, for example, the NHMRC or the ARC. Participant 12 was one of several interviewees to make the point that ministers may intervene after those councils have completed their extensive review processes and made recommendations to the minister as to how funding should be awarded. "Ministers have discretion to accept or reject the recommendation," the participant said. So, although it is rare for ministers to reject recommendations regarding funding, government-funded agencies are only empowered to make recommendations to the minister.

Regarding specific research priorities and projects given by the minister to funding bodies for management, Participant 22 stated that politicians prefer to support schemes that fund projects which are "shovel-ready", that is, sufficiently advanced that awardees can begin work soon after their funding is announced. Another political preference is for short-term grants.

The advantage of backing shovel-ready projects and short-term funding schemes is that ministers can use them as the basis of numerous public announcements. They could, for instance, issue a press release stating that a specific program will be funded, put out another press release when details are determined, yet another to acknowledge the launch of the project, and so on, virtually ad infinitum.

According to another participant, the strategy, noted above and analysed in Chapter 7, of providing funding to schemes and projects that will quickly lead to good news announcements helps explains why there is little political appetite for long-term funding, even for projects that that promise long-term benefit:

> [Long-term funding] is hard to come by because it's not going to be something that political, the politicians can say after two years, 'Look, we've done it'. (Participant 1)

There is evidence to support the claim about the political proclivity for multiple public announcements. This is demonstrated by the effort ministers put into communicating their activities to the public, as shown by the number of press releases they issue.

For example, when Parliament was not sitting from 3 to 26 August 2016, Greg Hunt -- then Minister for Industry, Innovation and Science -- issued 19 press releases.[134] Most

[134] See http://minister.industry.gov.au/ministers/hunt/media_releases

stated that the government would spend money on specific projects supporting "innovation", "collaboration", "entrepreneurship", "hi-tech manufacturing", and the like. But this was not money newly allocated to such areas, as the press releases implied in an effort to attract media coverage. Instead, it came from the $1.1 billion National Innovation and Science Agenda, launched with much fanfare by Prime Minister Malcolm Turnbull in December 2015.[135]

Political decisions also affect the continuity, or otherwise, of research schemes and the projects they support, as well as the duration of grants available for R&D projects and schemes. Previously funded projects, for instance, are often renamed and relaunched, or money previously committed to one project is used to fund a newly announced scheme. The goal is to obtain as much media attention and coverage as possible, while spending as little as possible.

Many participants cited politically driven short-term and on-again-off-again project funding as a significant barrier to innovation. The short time frame does not reflect the realities of the innovation process, they say. Three or four-year funding "isn't enough to do innovative things", said Participant 11. Participant 16 added that "There's a lot of important work which isn't completed within three years". Participant 21 expanded on the point:

> If I had a criticism of government innovation policy in Australia, quite acute now and has been in the past, is they don't recognise the time frames that you need to do this. And whether it's a policy or an activity there's a kind of a four years forward estimates time frame imposed on things that are actually, might take ten.

Building on this point, as well as comments in the previous section about political understanding of the innovation process, Participant 22 claimed chronic under-funding is particularly detrimental to the development of medical devices "which have a 10-year window". A good example is the original four years of bionic eye funding, another interviewee claimed. "In the scientific world you can barely scratch your knee in four years, [let alone] build a Bionic eye" (Participant 15).

In sum, the political cycle has a significant, often negative, impact on the amount of R&D funding available to researchers.

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135 See Chapter 2, *Innovation in Australia* and https://www.pm.gov.au/media/2015-12-07/launch-national-innovation-and-science-agenda

Funding bodies

In Australia the two long-established, government funding bodies are the ARC and the NHMRC.[136] Along with advising the government on research matters, the ARC administers the National Competitive Grants Programme, a significant component of Australia's investment in R&D. Similarly, the NHMRC administers a program of research grants. It also develops health advice for the government, health professionals and the public, as well as advising on ethical issues for clinicians and researchers.

Both agencies have maintained bipartisan support since they were established in their initial forms in 1946 (ARC) and 1926 (NHMRC). However, the amount of funding they are allocated annually for supporting research varies, depending upon the budget and priorities of the government of the day. Tellingly, the priorities given to the funding bodies also change, as do the interpretation of those priorities by the agencies. These changes contribute to the funding uncertainty faced by researchers because the bulk of R&D funding, as noted earlier, is provided by the Commonwealth through the programs of the ARC and NHMRC.

While interviewees acknowledge the ARC and NHMRC are the life-blood of research and early-stage development within Australia, they recognise that the amount of funding allocated to the agencies is insufficient to take many promising ideas to the commercial- ready stage.

> The NHMRC funding I thought produced good outcomes. But unfortunately, they don’t enjoy support beyond just the research end. (Participant 27)

One interviewee noted that while research institutes and industry can be named on funding proposals, the ARC does not permit them to received funding under all their schemes. They also claimed that it is not the role of the funding bodies to help teams take prototypes to market. As Participant 20 said, “The reality is that [government] can’t do everything”.

But the total amount of money available to the research councils is not the only issue impacting the innovation process. According to participants, the way the available money is distributed also compromises the research outcomes achievable. For instance,

[136] See https://www.nhmrc.gov.au/about/history-nhmrc; http://www.arc.gov.au/history-arc; and Chapter 2, *Innovation in Australia*.

participants argued that the bodies get the mix wrong when awarding grants; they underfund commercially-oriented areas of research:

> If you look at the total government investment in R&D in Australia, which is roughly around $9 billion, two [billion] of that goes into the industry programs, and that's why I used to get irritated. The problem is that the ARC discovery end is consuming too much frivolous money, and then there's just $2 billion sitting in the industry streams. (Participant 21)

Similarly, here is Participant 22:

> In reality the NHMRC and the ARC don't put huge amounts of funding into their commercial funding pipelines. NHMRC have a development grant process which is their commercial arm of the NHMRC. And it is funded less than 2% of the whole NHMRC.

While it is not a question of how the ARC and NHMRC distribute their funds, the same participant is critical of the fact that the councils do not have universal requirements for industry partners to contribute financially to academic-industry projects which have won grants. For example, although the ARC requires industry partners to make a contribution in cash and/or in kind when applying with university partners for Linkage Project funds, that is not the case for similar NHMRC schemes:

> The commercial partner does not need to put any cash in, and just needs to write a nice letter of support. You can get a nice letter of support from commercial partners even if they're not really commercially interested in the project. It would be nice to see a little bit of commercial leveraging of NHMRC dollars. (Participant 22)

Participants also argue that the funding bodies distribute available funds to too many applicants, with few individual projects allotted the full amount requested. The result, they say, hinders the advance of research projects which are frequently left struggling to find support when a grant runs out. Pointing to the ARC by way of example, Participant 20 said:

> We spread our money already very thinly. Even if you stagger your way through and get an ARC grant with a 1 in 5 chance, so you've been very successful you get some fraction of the budget you need. And that's because we try to fund so many all the time, at partial funding limits…So how do you get the best of a rationed resource [federal funding]? I don't think it's just spreading it very thinly and saying that makes us feel good.

Participant 21 also noted that, above and beyond the tendency to spread limited Commonwealth funds very thinly, the way funding proposals are assessed does not necessarily ensure the most promising proposals are supported. Speaking of the ARC Linkage program, which supports academic-industry collaboration, the participant claimed it inadvertently weeds out "innovative" proposals. For instance, instead of a "two-stage process" in which specialist panels separately review the quality of the science and the industry relevance before a final decision is made, the council has one panel which relies upon "aggregate decision-making … in a way that the really innovative doesn't get through the more conservative decision-making".

Participants touched on another, broader matter impacting the administration of ARC and NHMRC funding. By way of background, in Chapter 6, I cited a relevant finding by former Australian National University sociologist Grit Laudel (Laudel, 2006a). According to her, "shrinking university budgets" are no longer sufficient to support research beyond staff salaries.

The consequence of the reduction of Commonwealth funding to universities is that academics and administrators scramble to obtain project grants from the ARC and NHMRC to cover the cost of important research infrastructure. Participant 7 claimed this means the funding bodies cannot focus exclusively on supporting specific research outcomes through their funding schemes. Instead, too often, they become default supporters of university infrastructure, often through larger projects such as the bionic eye initiative. The participant said:

> The truth of the matter is that $50 million was not given to the groups that got the money in order to have a viable bionic eye at the end of the day, which was never going to happen. It was to fund tertiary institutions [to] build infrastructure, fund research, maintain research capability, train the next generation of research students, and this was a fun project for them to pursue during that. And that was the outcome. As long as no money was wasted, then people have been engaging in research, and that was the end in itself.

In terms of accountability, although the ARC and NHMRC check whether projects have delivered, many participants saw these mechanisms as inappropriate. They are viewed as time-consuming and not always relevant to assessing whether or not a grant was appropriately used in pursuing the project goal. Instead, accountability mechanisms are geared to the short-term political cycle. Participant 11 spoke for many:

> Of course, accountability is very, very important to us all, and we expect our governments to be accountable. We expect to have accountability for how our taxpayer money is spent. But if this accountability is taken to mean that

> you have to deliver the end result by a given time, rather than a continuum of results over time, then I think it will always hurt innovation. And that's pretty much what we see, for example, through the ARC process.

Overall, interviewees felt that the funding available to granting agencies such as the ARC and NHMRC is not sufficient to adequately support the innovation process through the R&D phase. They said too that the way the agencies manage the granting process is less than optimal. The most innovative projects are not necessarily supported, and those that are, often do not have sufficient funds to achieve their potential. Finally, interviewees thought grant accountability is time-consuming and inappropriate for many projects, especially those such as the bionic eye with long-term R&D requirements.

Funding the bionic eye initiative

Graeme Clark is famous for developing the bionic ear, or cochlear implant. But he was not the first to create a hearing prosthesis of this nature. That credit goes to F. Blair Simmons at the Stanford University Medical School.[137] Clark was, however, the first to effectively commercialise a device. And as Participant 17 said, he had plenty of support from the University of Melbourne, philanthropic funding, and long-running Commonwealth support:

> The government did in fact support the bionic ear early on, outside the normal funding channels as a national priority. And did in fact lead to development of the whole commercialisation project. And it was a succession of ministers from both sides of politics who backed that because it was seen as something worth doing. And that was not handled through the ARC or the NHMRC until much later.

It could be argued, then, that Clark may never have successfully commercialised the bionic ear had he been working on it today. As Participant 17 suggested, when Clark began work on the device, the Commonwealth provided greater support to universities such as Melbourne, enabling him to conduct his early work. He went on to receive grants from the federal government which funded the R&D, and gained support from both government and industry to take the product to market.[138]

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[137] See https://www.powerhousemuseum.com/hsc/cochlear/history.htm

[138] http://www.cochlear.com/wps/wcm/connect/au/about/company-history provides a concise history of the bionic ear.

In contrast, the story of bionic eye was very different. Although the early research conducted by the Sydney team -- covered in Chapters 3 and 5 -- was funded through conventional channels, once the field was singled-out by the Rudd government for significant support, the Bionic Eye project fell under the purview of the ARC as a Special Research Initiative (SRI). Even though it was set-up as a SRI, participants claim the structure lacked the flexibility the project needed for success. As Participant 20 said, the project "got squished into a process that it wasn't really fit for". Several participants agree, including one with industry experience:

> I never would have run it that way, because … there's just not enough money, and it's too difficult to do it [that way]. They're splitting things up too much. (Participant 26)

Plus, the structure made project management difficult, said Participant 19 who also has public and private sector expertise. The interviewee claimed it was hard to be an effective manager in the Bionic Eye Initiative because there was no corporate-style line authority, merely persuasion.

> I don't have a lot of levers to pull, I'm not a line manager of anybody. I can't award bonuses to people. I can't say we'll reduce your teaching because of this. I had a few more levers to pull as head of department. I think that was a useful thing.

Participant 18, also with industry experience, agreed the SRI framework was inappropriate for the Bionic Eye Initiative. The Participant suggested a non-governmental organisation, or a corporate entity would have been preferable:

> [But] that was too hard. I think they didn't have the guts nor the people to be able to do that from a government point of view. And it's a big gamble, to some extent.

It is a gamble that the government should have taken, according to Participant 23. The interviewee said it is the role of politicians to have the "foresight" to establish national projects and mechanisms for managing and supporting them beyond the "normal funding mechanisms" available through the ARC or NHMRC. As Participant 27 suggested above, even though the bionic eye had been identified as a national priority by the Rudd government, it was neither structured nor funded such that it could wend its way through the convoluted innovation process.

Additional criticism of the way the Bionic Eye initiative was organised focussed on what Participant 17 called "the rigidities in administration associated with the ARC process". Participants noted that the time spent following strict reporting guidelines, meeting key performance indicators (KPIs), and ongoing pressure to publish papers in order to bolster the project's impact measurements, kept them from more outcome-oriented research. It was a "waste of time and energy", claimed Participant 22.

Further, as discussed above, interviewees such as Participant 7 claimed administrative requirements placed upon bionic eye collaborators were not designed to ensure teams produced results: "The funding body's accountability was just to give the funding and make sure no fraud occurred".

Other interviewees with industry experience highlighted additional rigidities within the SRI structure. For instance, Participant 26 claimed the system made it difficult to purchase components from the private sector for the bionic eye prototypes under development during the initiative. Instead, they spent time and money building them in-house:

> It's utterly insane to me that people should contemplate building packages for active implantable devices, because there are quite a few companies in the US now that that's what they do for a living. And if you go to them and you say, 'I'd like one of these, this shape, this size, this number of feed throughs', and so on, they will say, 'Yes, okay, that's fine. It will take us four months to do that and it'll cost you $700,000'. And then you just buy it. You don't build it. You buy it because it already exists.

Representing the view of many interviewees, Participant 29 said the bionic eye initiative, like many government programs, was "under-funded from the start". As discussed in Chapters 3 and 5, the Rudd Government sought to use the initiative as an important public 'announceable' after its highly-publicised Australia 2020 Summit, convened in Canberra in April 2008. The primary goal was political success, a demonstration that the newly administration was active and governing well. Ensuring there was sufficient funding for scientific and commercial success was a second order matter.

Additionally, some interviewees claimed the government did not adequately evaluate the costs involved in taking the concept from laboratory to market when it announced the initiative. Participant 27 said that became obvious when the initial 4-year bionic eye funding of $50 million was divided between two consortia:

> What's happened is that the funding has been split so that both camps were racing to try and get a full product out of it. And with $50 million, you don't have enough to do two products. One product will take $200 million to bring it to market. And that was fundamental stuff for me. Blind Freddy would know that if they'd been in industry.

Participant 25 went further, claiming that a "commercialisation study" should have been conducted before the government created the Bionic Eye Initiative and provided the original 4-year, $50 million in funding:

> In other words, throwing $50 million at something at the front end, would that likely result in an outcome? Or maybe you need to spend $150 million, or maybe you shouldn't do it at all. And I guess my point is that I think for not a huge amount of effort you could have figured out upfront that just throwing $50 million at researchers wasn't going to result in much.

According to Participant 15, evidence that $50 million was insufficient was easily available. All the government needed to do was look at the amount of money spent on overseas bionic eye research such as that of the University of Southern California's Mark Humayun, co-inventor of Second Sight's Argus series retinal implants.[139] The Argus implant was the most advanced prototype at the time the Bionic Eye Initiative was established. It has since been commercialised in Europe, the UK and the US, and in 2017 its first prosthesis was implanted in Asia: "I mean Humayun presents [a timeline showing] it took them 17 years and US$200 million on his first slide, every conference he goes to."

Pointing out that since the end of bionic eye funding in Australia in 2014,[140] no prototype has gone to a clinical trial,[141] the participant added: "Yeah, anyway, there was going to be no money backing it up [at the end of the granting period], and so, therefore, it's just going to be dead in the water".

The lack of follow-on funding is a feature of so-called terminating programs such as the bionic eye initiative. These programs are designed to last a set period of time, regardless of whether or not they were established with realistic goals and funding. According to

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[139] See Chapter 3, *The Bionic Eye*, for a discussion of the development of the Argus implant.

[140] The initial 4-year grant of $50 million was extended for a year, expiring in 2014.

[141] See Chapter 3, *The Bionic Eye*, for a review of the progress of overseas projects and products. The chapter notes that prior to the announcement of the Bionic Eye Initiative a small group in Sydney was ready to go to an early clinical trial. The group split in two, and the original prototype never advanced to a trial.

Participant 10, this is a fact many researchers do not always recognise, or want to recognise:

> It's invariably the problem with terminating programs that researchers will believe the money is indefinite, the infinite continuing program, and won't necessarily recognise that the money was for a finite period.

While researchers can apply for other sources of funds when a grant ends, special programs like the ARC's bionic eye initiative have pre-determined lifespans, unless there is intervention at the political level. The bionic eye Initiative gained its additional year of funding through such intervention.

The above quote from Participant 10 supports the argument that funding for the bionic eye initiative was affected by the political environment. Decisions were made by politicians about the amount of money to be provided to the project and the mechanism through which the funds would be distributed and managed. It was a "political decision" said Participant 7:

> If the outcome was we want to efficiently … and productively build a bionic eye medical device, and we want to do that in a very evidence-base way by looking at all the evidence and seeing the outcomes of all the groups, working out who could be most successful in this area and then funding people appropriately, that was never, I guess, a plan from the beginning.

Summary

Based on my analysis of participants' comments, I find that significant structural barriers to innovation in Australia derive from the country's 3-year political cycle and the organisation of the country's R&D funding system. This is so, because the bulk of R&D funding comes from the Commonwealth government, with limited contributions from the private sector.

On the first point, participants expressed dissatisfaction with the impact the political cycle has on science and innovation policy. They noted that incoming governments tend to overturn initiatives established by the previous administration or change them substantially. Incoming governments also need time to develop understanding of the nature and dynamics of science and innovation, as well as a working knowledge of previous policies and projects.

These political realities make long-term planning difficult, for both governments, universities and government research organisations. Adding to the difficulty is the tendency for administrations to begin campaigning for re-election about half-way through their 3-year term. According to participants, this means politicians tend to support short-term projects and make policy decisions on the run. The result, they said, is an ever-changing policy environment.

On the second point, funding, participants feel constrained by lower levels of financial support throughout the innovation process compared to their international colleagues. Due to cutbacks to overall funding, universities rely on grants and non-Commonwealth funding to support infrastructure, as well as research. Funding from the private sector is minimal. Further, interviewees believed the political cycle puts politicians who manage science and innovation issues under pressure to respond to lobbying by interest groups in ways that adversely affect funding decisions.

Participants also felt that the 3-year political cycle creates a parallel short-term funding cycle. That is so, they claimed, because politicians, working towards the next election, seek to gain publicity through frequent policy and funding-oriented announcements. Re-announcing old programs, often under different names with a different emphasis, or announcing new short-term ones helps boost media and public attention. This occurs after incoming governments have chopped or changed schemes established by preceding governments. Both early and mid-cycle political intervention in funding matters does little to maintain the continuity participants said is critical to successful innovation.

While the primary funding bodies, the ARC and the NHMRC, continue to enjoy bipartisan, if not generous or consistent support, participants believed that ARC and NHMRC funding review processes pose their own barriers to innovation. Participants said, for instance, that the councils tend to spread the available money too thinly. Consequently, less progress is made on funded projects than could be expected if they were allotted the full amount requested by applicants. Participants claimed, further, that too little funding is dedicated to outcome-directed projects, as opposed to fundamental research. They argue that even commercial grant schemes such as the ARC Linkage Scheme and the NHMRC equivalent lack sufficient support.

In terms of the bionic eye initiative itself, participants felt it suffered from unrealistically low funding and a lack of rigour in the creation and management of the project. Several said the initiative was a product of political dynamics and, therefore, doomed to disappoint. Finally, several participants claimed the organisational structure established for the ARC's Special Research Initiative in Bionic Vision Science and Technology was not fit for purpose. It was, they said, too rigid.

Participant 3 spoke for many with the following comments: "Political leaders here are just dominated by short-term politics" and "We don't have enough money".

Chapter 9: Structural Barriers: Geography, People and the Valley of Death

Introduction

The word innovation has many meanings, from a product to a process. Throughout this thesis I have used the latter meaning, defining innovation as the complex, iterative process of creating and developing ideas and translating them into products. It is a process embedded in a system, a national innovation system. I have already argued that the political, academic, and industry arms of Australia's innovation system have evolved in an ad hoc manner, creating bumps, barriers, and detours, as products move from the laboratory to the marketplace.

In the previous chapter I reported findings from my qualitative study which indicate how aspects of Australia's political system and funding arrangements tend to create barriers to innovation. Here I discuss additional barriers which derive from the fundamental structure of the system and the nature of its components. Like those in the preceding findings chapters, the themes presented emerge from my analysis of participant interviews. I start with a section on *The Tyranny of Distance*, then examine *Australia's Talent Pool*, and *The Valley of Death*, from which promising products seldom emerge. I end the chapter with a *Summary*.

The tyranny of distance: "The closer the geography, the easier it is to interact" (Participant 5)

In 1966 University of Melbourne historian and economist Geoffrey Blainey published *The Tyranny of Distance: How distance shaped Australia's history*. Fifty years later the book offers a contemporary lesson: geographical distance affects more than the trajectory of a national story. It helps shape the structure of the nation's social, political, economic and intellectual systems.

According to interviewees, distance is a significant variable in the organisation and operation of Australia's innovation system. That is the case because the country has a comparatively small population, spread across a large continent. These realities influence the way collaborators work with one another and, therefore, the effectiveness of their partnerships in large projects such as the Bionic Eye initiative. As Participant 5 claimed:

> The closer the geography, the easier it is to interact. Although nowadays with the technology as it is, that, of course, has been overcome to some extent. But even so, the more local the collaborators are, then the easier it is to interact together. That doesn't mean it's going to be any more successful, but it's more straightforward to be able to interact together.

The participant's comment fits neatly with a wider discussion of the importance of spatial proximity in the innovation literature. For example, Swedish experts Björn Asheim, Lars Coenen and Jan Vang note that while "electronic means of communication have profoundly altered human communication patterns", face-to-face communications are vital to activities "where scientific knowledge is highly important". This is because, they claim, face-to-face communications build "trust relations and initial-idea spawning and brainstorming among fellow researchers" (Asheim et al., 2007, pp. 659, 661–662).

There was agreement on this point from several interviewees. Regular face-to-face interaction was reported to enhance the quality of working relationships. Participant 2 used the analogy of the difficulty of maintaining a long-distance personal relationship. "It's the usual thing with marriage, I guess, and the tyranny of distance".

Similarly referring to the tyranny of distance, Participant 28 said it posed a significant barrier for Bionic Vision Australia's (BVA) Melbourne-Sydney collaboration:

> I think the tyranny of distance has made things hard. Like as things move faster and it's easier to overcome the language barrier [face-to-face]. I didn't know that earlier, but we do have a language barrier between disciplines. So, the way that surgeons and clinicians talk is different to how mathematicians talk. It's different to how engineers talk. And that's difficult with [physical] distance between us. So, it's a lot easier to do that when you are sitting around a table together.

Participant 23 agreed that BVA faced such challenges:

> You do have people with different agendas and different priorities. So clearly, it's important to have a good working relationship which is hard to do when people are often just on the end of the phone or a Skype… and it was in multiple campuses, multiple institutes in multiple states. So, inherent in that is a lot of difficulty in organisation and project management.

Even when collaborators are in the same city or the same part of the same city, Australian institutions seem poorly setup to facilitate engagement, formal and informal. For example, Participant 19 was working overseas when the call came to return to Melbourne to be involved in the Bionic Eye Initiative:

> I was in Vienna, and they said, 'Hey, we've got to the next round [in the proposal review process]. You have to come back'. And I said 'Well, I'll come back if I can have a meeting room next to the restaurant because I want to encourage people to come to dinner, lunch I should call it, lunch and then continue discussions'.

This was a deliberate attempt to borrow from the idea of 'innovation precincts' which formed organically around innovation hubs like Stanford University in California and Boston's Massachusetts Institute of Technology.[142] One goal of precincts is bringing people together easily. In contrast, in Australian urban centres such as Melbourne, where both bionic eye consortia were headquartered, there are limited options for travelling conveniently from Point A to Point B across the sprawling city, let alone from various parts of individual campuses. This makes collaboration more difficult logistically:

> I've always said they need a tram system around Monash because they've got that at Silicon Valley, and you could hop on the tram and go and see the company down the road … and in Melbourne University when I worked there, they never had anywhere where anyone could park the car. And even

[142] See Cutler, T, The role of precincts in innovation systems – a discussion paper, 2009, for a discussion of the rise of precincts, both organic and planned. http://www.cutlerco.com.au/activities/speeches/09_speeches/Precincts_whitepaper.pdf

> the business development manager, if he went off campus, he could never park his car when he came back again. (Participant 19)

According to participants, then, physical distance between teams within the Bionic Eye Initiative hampered successful innovation. This was particularly problematic for BVA, which had collaborators in both Melbourne and Sydney. As well, participants felt that the many partners involved in both bionic eye consortia did not have easy access to one another, even when they were based within the same city. The physical distance between teams, and perceived logistical challenges in overcoming them, made project management difficult, especially in regards to resolving disagreements between team members.

The talent pool: "We've got to attract the very best talent that the country has" (Participant 10)

At 7,692,024 km^2 in size, Australia is the planet's sixth largest country after Russia, Canada, China, the USA, and Brazil.[143] In contrast, when it comes to population, based on 2014 statistics, the country ranked 56, nestled between Cote d'Ivoire and Sri Lanka.[144] And when it comes to the process of innovation, both factors are important, say participants in my case study. That is so because with a population of just over 24 million in 2016, Australia does not have as many potential and actual researchers and science-based industrial experts as do innovation powerhouses such as the US, Germany, or Korea, let alone emerging players like China.

But additional barriers to innovation lurk beneath the fact that the country has fewer people employed in research and development (R&D) than its scientific competitors. Among these are a dwindling pool of mid-career scientists and insufficient recruitment of overseas talent, along with significant gaps in expertise within the innovation system. I discuss these hurdles below.

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[143] See http://www.ga.gov.au/scientific-topics/national-location-information/dimensions/australias-size-compared.

[144] See http://www.indexmundi.com/g/r.aspx.

The leaking talent pool

Participants said it is worrisome that Australia's relatively small talent pool is being eroded due to funding pressures, such as those discussed in the previous chapter, as well as in Chapter 6. Participant 24 highlighted the situation within medical research:

> The people who are feeling the pinch the most, of course as we all know, are the people in what's called the middle … not those starting out or not those like myself at the end, but those in the middle. And they're the ones we've put in, say for example, 10, 15, maybe 20 years training as a country, but we're at risk of losing them, either overseas or they go do something else.

The participant added that these mid-career researchers are "totally essential" to innovation:

> Because if we're not careful and we lose them, you have got to build them up again from younger people. And by that time, and when you are doing that, the older people have retired so you won't have that mentorship on the way. I mean it's really at a very critical stage.

Numerous participants agree with Participant 24 that Australia needs to support the R&D talent it has. It must maintain a healthy innovation ecosystem that includes early, mid, and late-career researchers. Further, because Australia's comparatively small research talent pool is leaking, primarily from the middle,[145] several interviewees believed the country must not only plug the leaks, it must also attract researchers from overseas. They said the nature of the funding system makes both tasks more difficult. For instance, in terms of attracting overseas researchers, Participant 16 was particularly critical of short-term funding:

> It's difficult to get talented scientists internationally to move to Australia for a three-year or a short-term grant. They need to have the opportunities to build a career, or to keep working in the same field for some time within reason.

The result is a talent squeeze. Ironically, the squeeze can be tightened by large multi-organisational projects such as the Bionic Eye initiative, which draws talent from other projects. According to one participant, there simply are not enough qualified people to go around, especially as many are leaving the field or moving overseas. "This is horribly controversial, and people will probably kill me for it, but sometimes when the

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[145] I will discuss this issue in greater detail in Chapter 10, Recommendations.

government sets up big initiatives it sucks a lot of talent out of the talent pool" (Participant 19).

Other interviewees were not as explicit, but several noted that there are already few people with experience managing and advising on conventional projects in Australia, let alone Participant 19's "big initiatives". That is, as I discuss in the following sub-section, they believe the talent pool is not only small, it is shallow. Australia does not have the right mix of expertise across the nation's innovation system.

The right mix

Australia's innovation system is just that, a system. To function at its best, any system needs to have all the necessary pieces in place, operating as smoothly as possible. As noted above, several of my participants claimed that Australia is missing critical human elements, that is, people with the right mix of skills needed to create and develop ideas and take them from the laboratory to the marketplace.

Leadership skills were raised several times by participants, most frequently in reference to BVA, the larger and more geographically dispersed of the two consortia funded through the ARC's Special Research Initiative program:

> [BVA] in my view suffered from a lack of a competent project planner as such. It's such a complex project and there aren't a lot of people who could get their head around all the things that need to be done. I think [name withheld] did a sterling job in understanding what he understood, but the overall program, it's a big job. There aren't a lot of people who've got that knowledge or background or skills in Australia. (Participant 27)

This situation does not surprise Participant 6 who said this is common in special research centres which bring together small groups under a manager or project leader. The reason is that management is "foreign" to most scientists handed the job. Only recently are universities and public research bodies beginning to provide opportunities for young researchers to gain basic management skills:

> Scientists by and large are not well trained in management. <laughs> They haven't got their MBAs, and often in a case where they have brought in a manager of a centre, independent of the scientific director, there's clashes there and there's people who don't understand the culture in the same way. So, I think the management of big science is a problem, particularly when big science has come out of straight science. (Participant 6)

Learning these “foreign” management skills on the job is, of course, possible, but that takes time and does not necessarily lead to solid mastery of the necessary expertise. For instance, Participant 19 noted a practice observed amongst scientist managers -- a propensity to manage upward, that is to spend more time promoting oneself to superiors than effectively managing people on the project or in the centre:

> I have seen leaders whose main aim in life is to please the board, rather than sort of get the project running well. And that's in all walks of life. So, a lot of people just look to the next layer of management and have to keep them happy.

Speaking of layers of management, the shortage of skilled leadership goes beyond research project management. It extends, interviewees say, to finding appropriately experienced individuals to fill the boards of directors of research projects such as the bionic eye initiative or scientific organisations.

Boards play an important governance role, providing oversight of the activities of a project or organisation. Board members may be well qualified scientifically, but if they do not have sufficient leadership skills to work constructively with both researchers and management of the project or organisation, outcomes can suffer. This was the case with BVA, as discussed in Chapter 5.

In addition, Participant 6 said advisory boards may be unable to give the sort of advice they should be giving, or are expected to give, to directors or researchers when they do not have the expertise to manage bias and influence due to personal relationships. This situation may arise, the participant said, when there is a “rather cosier relationship” between the board and director than is desirable for objective and effective guidance.

This does not necessarily imply a conflict of interest. It is largely a consequence of Australia’s small talent pool. There are simply fewer qualified individuals available to serve on boards, compared to more populous countries. That means that people with some knowledge of the area in question are likely know one another, personally or professionally.

Participant 6 added that constructive oversight may also diminish when boards hold just one or two meetings a year. This is common, especially when board members are overseas or have numerous professional obligations. “It isn’t sufficient”, either for being available to project directors or for acquiring sufficient knowledge to provide useful oversight, according to the participant.

That latter point was echoed by Participant 27: "You really need people on the board who understand the area intimately". This is extremely important in areas such as biotechnology where research leads to new products or processes that must go through complicated national and/or international regulatory process before they can be marketed.[146]

But government-funded researchers and research groups are not alone in lacking in-house management expertise. Industry too does not always have the right mix of people on staff. In particular, there is a dearth of people able to collaborate with the research sector. While participants did not comment directly about this issue, it was a key finding from a 2016 report by the Australian Industry Group (AIG).[147]

The organisation interviewed and surveyed people working in science and technology based businesses, from small to large. The goal was to determine what the industry sector sees as major barriers to innovation. A key finding of the AIG report was that "Collaboration with universities is hampered by a lack of skills and time among smaller businesses" (AIG, 2016, p. 11).

The situation for both the research and industry sectors is worsened by the fact that there are few experts able to work between academe and industry. Following Participant 27, I call such experts 'intermediaries'. Intermediaries have working experience in both the academic and industry arms of the innovation system. As Participant 23 explained, they are not "just people in white coats, but people who were small businessmen as well".

Chapter 7 discussed in detail the observation by numerous participants that academe and industry are different, often clashing cultures. Members of the two camps have different goals, expectations and ways of working. In leading innovative nations such as the US, intermediaries are regularly "taking stuff from one side and depositing it in the other side", said Participant 27, who has both academic and industry experience. The participant spoke for other interviewees:

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[146] I will note the impact of regulations in The Valley of Death.

[147] I discussed the report in Chapter 2, Innovation in Australia.

> They sit with a leg in both camps and understand the value of both sides. And in Australia there are extraordinarily few people who even understand that there is a role there. [That] what you need is a trusted intermediary. And there's a career in being a trusted intermediary in some countries, but just in Australia there's very, very, very few people who do that work.

Additionally, as Participant 23 claimed, while there is growing recognition in the university sector that intermediaries can play a vital role, "there's no infrastructure to pay for people to help us do that". That leaves many scientists at the whim of chance when they seek to collaborate with industry. "At the moment, it's very difficult for a researcher to know how to go forwards, unless they have done it before, unless they magically find someone that is interested to help them" (Participant 23).

There are good reasons why there are few people with such skills in the research sector. As discussed in Chapter 7, there are few, if any, incentives for academic scientists to work between academe and industry, to learn how each sector operates. Participant 22 agreed. "At the moment, there is no incentive for young researchers … that want to stay in the academic stream to work with commercial colleagues."

In fact, there are disincentives to doing so. In chapter 7, for instance, Participant 19 told of being actively discouraged from returning to academic research after time in industry. "Nobody wanted to know" how to establish and run a start-up venture. As well, chapter 7 highlighted the need for researchers to focus on publishing papers and obtaining grants. Spending time in the private sector can interfere with meeting those metrics and building a career. The consequences are clear, said the participant.

> We don't have the expertise … We don't have the training on how to actually go forward to approach commercial ventures.

The 2015 launch of the National Innovation and Science Agenda did, however, help focus the attention of government-funded universities and research organisations on scientific translation. It may encourage the early efforts by some University and research organisations to develop training programs for staff and students engaged in applied research. I will discuss some of the more promising approaches in the next Chapter, *Recommendations.*

The valley of death: “There’s a valley of death in Australia that is very real” (Participant 18)

Introduction

A report of the British House of Commons Science and Technology (2013) put it succinctly:

> There exists the concept of a valley of death that prevents the progress of science from the laboratory bench to the point where it provides the basis of a commercially successful business or product. (p. 3)

A 2009 Australian government policy document added to the perspective from the UK:

> The passage from experimental development to commercialisation is so treacherous that high-tech start-ups call it the valley of death. (Government of Australia, 2009a, p. 47)

In Australia, the valley of death is also known as a ‘black hole’ or the ‘gap’ between fundamental research and commercialisation. Like Participant 18 above, Participant 4 recognises the trap the valley holds:

> There is this gap in the middle, I guess, where the government says, ‘alright, well we’ve given you all of the resources that were necessary to get you to a certain point, now you need to go forth and enter into the area of commercialisation’. And there’s a valley in between the two. It’s in between the people on the other side willing to invest [and] the people on this side [who] have invested already.

Participant 9 described the human context of the valley of death:

> The challenge of then converting an idea that’s developed in the lab into a product that someone can use is extraordinarily complex and extraordinarily challenging, and primarily done by the private sector. And so, there’s a transition period between [government] funding through to private sector funding. And the valley of death is fraught with different accountabilities, different responsibilities, different intentions.

Even when ideas do cross the gap, time spent in the valley of death delays the journey from laboratory to market. “Everyone wants this to happen faster,” wrote physicist Cathy Foley, Deputy Director and Science Director of the Manufacturing Flagship at Australia’s Commonwealth Scientific and Industrial Research Organisation.

Considering that it takes on average 20 years for ideas to travel from laboratory to market, the hold-up can be considerable (Foley, 2014).

Several interviewees claimed that if ideas do emerge from the valley of death in a timely manner, the reason is all too frequently because they have been exploited by overseas firms. Critically, it is not just a great idea that travels abroad, it is usually intellectual property (IP) in the form of a patent that is plucked from the valley of death. I discuss IP in more detail in the sub-section below. Participant 6 offered this assessment:

> There clearly is a barrier between doing the creation of IP and then converting it into a commercial [product] in the commercial realm within Australia. I mean, as you know, too many of the patents get picked-up by overseas firms. So, the idea that we are going to produce a patent, and then it's going to be a home-grown industry come out of it is almost non-existent, I think.

This fact of losing ideas and IP to international interests has a long tradition in Australia. For instance, there was the loss overseas of David Warren's 'red egg', the precursor to the black box which was developed by the British. American corporations even reaped the economic benefits of Australian Howard Florey's development of the first viable penicillin drug.[148]

> We've invented so many things, from the black box on, but we've never commercialised them here so that we'd benefit. That's our difficulty. Sure, some of these ideas have gone offshore and they've been introduced, but the commercial side of it hasn't been done here. And that's where I think our weakness is. (Participant 3)

That is an important point, one bolstered by the recent AIG report: "Less than one percent of the world's innovations are realised in Australia", and the authors concluded that "[Australian] innovations may be successful, but commercialised overseas" (AIG, 2016, pp. 7, 18) Speaking for several interviewees, Participant 23 agreed: "Australia is very good at research, but we're hopeless at commercialising it".

The constraints on funding which I discussed in the preceding chapter play a pivotal role in condemning many potential products to a prolonged or terminal fate in the valley of death. The Commonwealth does not see its role as supporting the commercialisation

[148] See Chapter 2, *Innovation in Australia*.

process beyond the R&D stage, while private sector investors are reluctant to support early-stage ventures.

As Participant 17 observed, there are "plenty of small start-up companies in Australia that struggle to survive". Other interviewees made the same point:

> A lot of projects have got right to the wire and then just run out of money and died. A lot died on the vine in the last 10 years. And that's where government support would really have helped. (Participant 27)

Referring to medical research Participant 22 said:

> So, we almost all the time have projects that are in that valley of death, and we're looking at all sorts of funding models to try and get them out of the funding death and into patients.

Innovation and policy experts tend to agree. There are high hopes that the Turnbull government's National Innovation and Science Agenda will support efforts to take ideas across the valley of death. But experts caution that such support must be both appropriately funded and fit within the wider context of the national innovation system.

In that regard, Participant 9 observed that past efforts designed to help early-stage ventures were well-intentioned but flawed. They funded too many projects inadequately, and failed to help the venture participants acquire the necessary skills to bridge the gap.

> [There were] really good initiatives done in the 1990s to commercialise ideas out of universities, but what it did too was to create a whole stack of sea turtles, baby sea turtles who were thrown out into the wild hoping for them to be nurtured by the great oceans of the world … [but they] never had enough money to go through the real commercialisation, valley of death process, never had the right intellectual and commercial governance, and the right people in their companies to help guide them, and then the investment community said …these are too risky.

The interviewee did note, however, that some baby turtles could have survived with appropriate funding:

> But the innovations that could make step change or marginal improvement, were lost, because there just was not enough capital provided to them. And it's a real shame.

In terms of the private sector's reluctance to invest in helping innovative products and processes across the valley of death, two interviewees, both with industry experience, cited the tax system as a barrier. "[It] prevents people re-investing in start-ups in the earlier years", said Participant 19. By way of explanation, Participant 5 pointed to frequent changes in government policy regarding tax concessions. These most often concern the amount of tax offsets, or rebates, firms can claim for R&D expenditures and the types of R&D activities for which offsets are allowed. Here is Participant 5's observation about what happens when tax policy shifts:

> That would cause investors concern in terms of a changing, the changing ground in regards to investment. If, for example, there are incentives provided through tax and so forth to investment in research and development, they can change.

In addition to changes to government policy concerning private sector tax concessions for supporting R&D and early phase start-up firms, another participant criticised examples of what are seen as overly complex accountability for the concessions:

> Labor brought some changes in that made the restrictions of what R&D was very, very tight, and they increased the compliance. We actually had to employ someone fulltime just on the compliance side, just for that legislation. It's that sort of stuff. And it's not productive work. That's just busy work. (Participant 25)

Other interviewees agreed that while risk aversion, insufficient funding, and bureaucratic and audit hurdles are the fundamental causes of the valley of death phenomenon, additional factors are at play. One is the suite of complex regulatory hurdles faced by new biomedical products such as the bionic eye. Another, disputes over intellectual property (IP). I begin with *Regulatory Hurdles.*

Regulatory hurdles

Creating and commercialising a biomedical product, in particular, is a long and complicated process. Not only do the inventions need to cross the valley of death, they are also subject to specific requirements to get approval to sell the product.

Take the case of one of Australia's most well know medical devices, the cochlear implant (bionic ear) which I discussed in Chapter 2. The story began in Melbourne in 1967. It ended in 1979 when Clark and his team at the University of Melbourne joined forces with medical devices firm Nucleus, and, with additional financial support from the Australian government, began manufacturing and selling the implant. That is 12 years. Arguably, the process could have been longer had the current regulator, the Therapeutic Goods Administration (TGA), been in place in 1979.[149]

Interviewees with extensive industry experience cited the pre-market approval process as one reason why biomedical products linger long in the valley of death … or perish there. As Participant 8 stated, "So there's the inventing part of it, and then there's the regulatory side of it". And the "regulatory side" is a burden, one generally tackled by industry not academe, said another interviewee:

> People have to understand the burden, the regulatory burden, that a new [biomedical] product has to go through. And people need to understand that you do the research … as far away as possible from the regulatory environment. And the regulatory phase occurs which is the product development stage. That needs to be done in industry, not the university. The research done in universities with industry involvement, but product development in industry, which is what happened with the cochlear [implant]. (Participant 27)

Numerous participants agreed that although strong oversight is needed to ensure the products are safe, the regulatory process for biomedical products is overly complicated and time consuming. One interviewee was highly critical:

> We regulate ourselves more and more and more. That makes change difficult. So, for example, you've heard me -- maybe you haven't heard me – but I complain about how we regulate medical devices through the TGA in Australia, and why it's so difficult for us to maintain manufacturing in Australia. (Participant 25)

According to the interviewee, the process is so slow and cumbersome that it affects not just the fate of promising new products in Australia, but also future sales in global markets. That is so, the participant said, because it "takes longer" to gain regulatory approval in Australia than in important overseas markets. That may not have been significant a few years ago, but it is today:

> Now we have dozens and dozens of other countries around the world in these emerging economies. They have grown up and they are regulating their own medical devices now. And they want country of origin approval before you can even apply to get approval in those countries. So, we can't

[149] The TGA was not established until passage of the *Therapeutic Goods Act 1989*. The cochlear implant was given FDA approval in the US in 1985. See http://www.cochlear.com/wps/wcm/connect/au/about/company-history

> even apply in India to sell them [product name withheld] until we get approval from the TGA … When the TGA is very, very slow, now that impacts our ability to market in dozens of other countries against a European competitor who gets timely [approvals]. (Participant 25)

The participant provided an illustration of the issue:

> We had a key product that we needed to launch through Asia. It was approved in Australia 14 months after it was approved in Europe.

Clearly, with several overseas offices the participant's company is large enough to take new products across the gap with less disastrous results than most biomedical ventures. The company has its own resources and can attract funding more easily than small early-stage endeavours.

The participant's comments, though, underscore the fact that participants feel that regulatory hurdles pose a significant barrier in the innovation process as it operates in Australia, as well as impeding businesses seeking to market products abroad. Regulatory hurdles are one reason that many potential innovations get stuck in the black hole between experimental result and commercial product. According to interviewees, so too are the costs and complexities of handling intellectual property which I cover next.

Intellectual property

The World Intellectual Property Organization (WIPO) is based in Geneva, Switzerland. It identifies itself as the global forum for intellectual property services, policy, information, and cooperation. Australia is one of 189 member states of WIPO and follows its conventions.[150]

According to WIPO, intellectual property (IP) refers to "creations of the mind". They range from inventions and literary and artistic works to designs, symbols, names and images used in commerce. IP is protected in law, through patents, copyright and trademarks which allow the holder of the IP to "earn recognition or financial benefit" from what they have invented or created.

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150 See http://www.wipo.int/portal/en/.

While there are several forms of IP, the form sought by those engaged in R&D and translation is usually the patent. A cursory look at WIPO's explanation of what a patent is begins to reveal why IP plays an important role in Australian innovation:

> A patent is an exclusive right granted for an invention, which is a product or a process that provides, in general, a new way of doing something, or offers a new technical solution to a problem. To get a patent, technical information about the invention must be disclosed to the public in a patent application.[151]

In its 2016 report, the AIG interviewed "leading innovators" with five Australian based companies: Leica Biosystems, Planet Innovation, Pollenizer, Siemens, and Signostics. Here is a comment from Leica Biosystems about the role of IP in the innovation process: "Intellectual property arrangements can be extremely important and a source of major friction if there is a clash of expectations in later stages" (AIG, 2016, p. 34).

The comment could easily have come from one of my interviewees. Many, from across the innovation spectrum, said disputes over IP are a serious barrier to innovation. Fierce IP disagreements occur within public research organisations and universities, between them, and between them and potential industry partners, just as the Leica Biosystems comment suggests.

Arguments about IP interfere with collaboration. They leave viable prototypes in the valley of death for years, often forever. To illustrate the nature of the disputes, Participant 15 outlined the "patent issues" which emerged as potential collaborators in the Bionic Eye Initiative negotiated with one another about IP, prior to submitting proposals for funding:

> Patent issues means that they had some patents, we had most of the patents, who owns what patents, who is willing to share patents that already exist, how do we share patents in the future, difficulties getting multiple universities/companies/countries deciding on who owns patents, blah, blah, blah. Everyone wants the patents. No one wants to share … It is like dealing with children. If you don't share, no one gets the toy.

The reason "everyone wants the patents" is that, as stated earlier, a patent is a legally enforceable right to exploit an experimental result or prototype. To quote Participant 24, patents are a "method of protecting stuff" and a "pathway to innovation". Patents are

[151] Ibid.

also the routes to profits should a patented product become successful in the marketplace.

But taking out a patent on a possibly useful or profitable finding is an elaborate and expensive endeavour. It is also time-consuming. According to patent and trademark attorney Jonathan Lewis with Brisbane firm Cullens, the time between filing and receiving a patent is often 3-5 years.[152]

The process is sufficiently complicated that IP Australia, which operates the nation's patent office, notes that if individuals do not want to handle the process themselves they could employ "an attorney or qualified person".[153] As to costs, the ABC television program The New Inventors provides estimates:

> The cost of an Australian standard patent including attorney fees is usually between $5000-$8000. Annual maintenance fees are payable from its fifth year. Over a 20-year term these will add a further $8,000 to the cost.

That puts a heavy burden on individual scientists or small teams who may lack the support of their employer or of very rare early-stage investors:

> There is a big funding gap at the translation point where you've got an idea and you need to take a patent out and protect it. There's no real models that are simple for doing that patent protection and funding that, apart from the university which doesn't really have the money, and it's probably not appropriate. (Participant 2)

The implications of IP hurdles go further than complexity and cost. As Participant 15's observation above indicates, conflict over IP can put a halt to ongoing research or consign experimental products or prototypes to oblivion. That is so because it can take, literally, years to reach agreements between stakeholders about how the IP is to be shared and exploited.

One interviewee said participants in the BVA consortium spent "12 months negotiating with each of those partners as to what we should do". It was an intense multi-institution, multi-disciplinary, interstate dispute:

> I think the potential for disagreement was always there, and the interstate rivalries were very clear from the start when NSW wanted to [hold the

[152] See http://www.cullens.com.au/general/how-long-will-it-take-to-get-my-patent/.

[153] See https://www.ipaustralia.gov.au/understanding-ip/getting-started-with-ip/ip-explained.

patents and] be the arm for commercialisation. And unless that was agreed, they would not proceed to apply for the funds on the ARC. So that was an absolute condition of agreement. (Participant 17)

After much wrangling, the BVA conflict was resolved. Another participant described the outcome:

> BVA holds the rights to license any of the IP that we and all the other partners have generated in the field of bionic vision. And so, I think that's nice, and from my perspective, neat. And so, BVA now has a commercial organisation called Bionic Vision Technologies, and Bionic Vision Technologies' role is to, on behalf of all the parties, go out and look for real commercial partners knowing that they have in their hip pocket the IP that, as a group, we collected. (Participant 22)

The BVA was not alone in experiencing IP conflicts. Here is an example of a disagreement within a small multi-disciplinary team:

> [Name withheld] was insistent on owning the bulk of it [the IP]. I understand that … It's just that our part of the deal, we were basically going to do a whole lot of work in developing this, and, in the end, from that part of the project we got really nothing out of it. Which to me isn't such a good way of doing business. (Participant 8)

Referencing their experience with the Bionic Eye Initiative, interviewees claimed that negotiating IP rights is especially difficult when dealing with international teams or businesses. "We didn't have any international collaborators directly in the project," Participant 22 noted:

> We thought we had the, and we still do, the technical capabilities within Australia to cover the project. But it would also perhaps be an issue of IP ownership and so forth that might have got a bit more complicated with overseas partners.

Similarly, Participant 23 talked about negotiations with the US firm Second Sight regarding partnering with one of the Melbourne consortia. This was after the unsuccessful Second Sight-Queensland bid for funding under the Bionic Eye Initiative:[154]

> Many of our researchers went over and toured their sites. We met their patients at meetings. We did as much as we could in terms of finding out what they were doing, and we also attended FDA [Food and Drug

[154] See Chapter 3, The Bionic Eye, and Chapter 5, Revised History, for details of Second Sight's role in the Bionic Eye Initiative.

> Administration] meetings where they presented all their results and their risks. But in terms of a formal collaboration, they were very keen to access our IP, and we did not feel that they had anything necessarily that would benefit us by us giving away what advances we did have.

Australia's IP system is not just complicated, costly and frequently the subject of disagreements between stakeholders, several interviewees criticised the level of expertise available to manage the "patent issues" listed above by Participant 15. Here is an assessment from an interviewee with industry experience:

> At [name withheld] I used to buy licensing or buy results of academic research. And the people selling the research don't have a clue. (Participant 26)

The interviewee offered an example of talking with a research group about taking on some contract work, building on patents already filed by the interviewee's organisation:

> And we ended up in the long, protracted discussion -- that we walked away from -- about who was going to share, how we were going to share the intellectual property. And I sort of said: 'Well, we're not sharing. We own it. Well, we'd like some of it. Well, you might like some of it, but we own it, and we're not giving it up'. [laughs]

Participant 8 is equally critical of the level of IP expertise within Australian universities:

> When universities get involved in owning intellectual property and trying to manage it, many of them, in my direct experience with [name withheld], have no clue about how to do that. And I say that now as the inventor of around 30 issued patents. I've been around the block a few times. I've done this before.

Findings from the AIG report support these observations. Industry experts told the group that, from their perspective, the generally poor level of IP expertise within public sector research organisations can pose "serious barriers to collaboration":

> Universities often approach IP in seriously inconsistent ways, with a confusing mass of idiosyncratic contracts and internal procedures that can be expensive and time-consuming for businesses to navigate. (AIG, 2016, p. 38)

Such comments fit with those from interviewees, dissatisfied with the way universities handle patentable research results obtained by their scientific staff. According to Participant 7, a contributing problem is that university IP policy is "heavily biased in the institution's favour" and "milks" scientists' advances: "There was no use innovating at the university because they really wanted everything, and they didn't provide much". Others held a similar view, among them Participant 2:

> [Universities] want to sort of, you know, try to stitch-up IP. And then there's a lack of incentive for the inventors and for investors because of the complexity of the university legal process.

University IP processes go beyond being complex and variable from university to university. From the scientists' perspective, they are often far from transparent. Here is one interviewee's experience:

> There was an intellectual property policy that was hard to understand. It was hard to get an agreement with the university so that there was some predictability going forward, so that then we could interact with industry in a predictable way. It was hard to get the university involved in negotiations in interactions with industry. It was almost much cleaner to just do all that separately. (Participant 7)

Not surprisingly, Participant 7 said of universities: "They don't do much with [experimental findings] themselves, and they don't let you do much with it yourself, so it ends up in a black hole". The following statement from Participant 15 epitomises the attitude many interviewees held towards what they see as the complex, time-consuming, conflict-riddled manner in which Australia's IP system operates: "Greed, in the end, fails even the greedy".

Summary

Tanya Monro is the University of South Australia's Deputy Vice-Chancellor of Research and Innovation. Speaking to the online public policy and business website InnovationAus.com, she offered her thoughts on what stifles innovation in Australia: "What kills innovation is internal competition from structures that drive conservatism," she said (B. Head, 2016). Her point that there are structural reasons why researchers, in both academe and industry, are often reluctant to take risks with R&D and translation reflects the findings presented in this chapter, as well as the previous one. Structures of the nation's innovation system impede the process of developing and commercialising products which are new to the world.

Chapter 8 reported the impacts of politics and funding on Australia's innovation system. This chapter reports findings from participant data and selected sources about structural barriers created by Australia's geography, its smaller scientific population, and the innovation-sapping valley of death.

Participants claimed the fact that Australia is a geographically big country heavily impacts the nature of large multi-disciplinary, multi-institutional collaborations. This is because it is easier to share goals, language and ways of working when people have easy and/or regular contact with one another. Participants felt, for instance, that geographical distance between research teams in Melbourne and Sydney had a negative impact on the ability of the BVA group to work effectively.

And interviewees noted that even within cities, collaboration can be difficult. Australia's University campuses, they claimed, are ill-suited for frequent contact between collaborators. This situation contrasts with so-called innovation hubs in places like California and Massachusetts which have developed in ways which encourage largely effortless interaction between researchers and industry.

In contrast to barriers posed by the size of the country, the key points of the section exploring Australia's talent pool derive from the country's comparatively low population. Fewer people are available to fill the innovation talent pool than reside in more populous nations such as the US. Additionally, there is a brain drain occurring as researchers, especially those at the mid-career level, pursue more stable and promising career paths overseas or outside academia. The lack of stable and promising career paths likewise makes it difficult to attract overseas researchers to Australia, participants claimed.

There was widespread agreement amongst participants that few academic researchers understand how to work with industry to translate experimental findings into commercial products. Nor are they encouraged or trained to do so. Conversely, there is evidence that small to medium-sized science and technology enterprises do not have the expertise to work well with university researchers.

Further, academic scientists promoted to management positions often lack appropriate leadership and management skills, said participants. Additionally, Australia has few skilled intermediaries, people able to help overcome these deficiencies by working with universities and government-funded research bodies, as well as the private sector. Overall, said participants, the nation does not have the right mix of expertise across the innovation system.

Finally, nearly all interviewees claimed that a "valley of death" exists in Australia, one into which potential products go to die or stagnate until they attract sufficient funding to take them to market. Many participants argued that although Australian research is we regarded internationally, the country lags significantly behind comparable nations in its ability to commercialise experimental results and prototypes. Much applied Australian research is commercialised overseas.

Focussing on biomedical products, problems cited by interviewees include what they see as an important, but overly complex process of gaining pre-sale approval for products and devices from the Therapeutic Goods Administration. They also express concern that the process of acquiring legal protection for all innovative science-based products is complex, time-consuming, and expensive. This is a major barrier, especially for early-stage enterprises.

The list of barriers to innovation identified by participants in this thesis is long, varying from the cultural to the structural. By looking at these barriers within a broader context it becomes possible to recommend changes which, taken together, may enhance the performance of the innovation system overall. That is the goal of this thesis, and I take up the discussion in the next chapter, *Recommendation*s.

Chapter 10: Recommendations

Introduction

Australia has a problem. As discussed in Chapter 2 and noted in the Findings chapters, the quality of the nation's research rates well on international rankings, but its ability to take potentially commercial findings through the innovation process to the marketplace is weak. To quote industry consultant and strategy advisor Terry Cutler, Australia's science and innovation system is characterized by a "strong focus on the 'R' side of Research and Development and benign neglect of the 'D' side and the market side of ingenuity" (Cutler, interview, 7 July 2014).

In this chapter, therefore, I make recommendations aimed at boosting the 'D' side of the innovation system and enhancing the nation's ability to maximise the benefits of its intellectual activity, commitment and investment.

My recommendations involve active participation by government as the sector of the innovation system with policy oversight and primary financial responsibility. The National Innovation System (NIS) literature consistently shows that integrated, productive national systems require government intervention, as appropriate to the individual nations. The recommendations also encompass universities and federally-funded research organisations, as well as the private sector. The recommendations are geared to enhancing successful innovation across Australia's innovation system.

My recommendations build on the barriers identified by my participants, and are thus drawn from experiences with the bionic eye initiative and other research projects. They also reflect barriers identified through my analysis of the texts, from scholarly and expert analysis and from commentary. Comparison of these two data sources produce to a clearer picture of Australia's innovation system than either source would on their own.

The recommendations fit within a system-wide view, as supported by the NIS framework. That is, they complement a suite of integrated policy actions geared to supporting Australia's R&D and to enhancing successful translation. To quote economist Elizabeth Webster: "It takes an amalgam of polices for a country to push ahead where others languish" (Webster, 2015).

To that end, I offer my recommendations as a policy mix. Such a mix comprises a blend of "innovation policy instruments" designed to solve problems of the wider innovation system. This is a suitable approach because the system I explore is shaped not just by structural constraints such as the political cycle, but also by the policies, people and programs operating within it (Borrás & Edquist, 2013, p. 1513).

My recommendations, then, flow across Australia's innovation system. While similar recommendations have been suggested previously in a range of government-initiated reports and reviews, they have not been pulled together as an integrated whole. Rather, they have been offered as solutions to problems identified in the part of the system under evaluation with little or no reference to the impact – positive or negative -- they may have on others.

Further, adoption of past recommendations has been selective, depending upon the political ideology of the government of the day.[155] I argue that the prospects of seeing positive changes to Australia's innovation system are enhanced by the existence of a system-wide, evidence-based policy mix such as the one I offer here.

Specifically, my recommendations -- Borrás and Edquist's "policy instruments" -- target four broad themes. These are: Lack of Continuity, Funding, Collaboration, and the Translation Environment. These themes emerged as logical organising principles for making recommendations, following the systemic approach of the NIS framework – here, a combination of interview findings with trends, details and insights obtained by a careful reading of policy documents and other text sources.

Recommendations listed under <u>Continuity</u> deal with difficulties academic and industry participants face because of frequent changes in governments and government policy. <u>Funding</u> includes recommendations tailored to help academic and industry stakeholders better support, plan, budget for and manage their activities. <u>Collaboration</u> recommendations address problems created by the differing academic and industry cultures, as well as barriers to productive collaboration, primarily within academe. Finally, in <u>Translation Environment</u>, I make recommendations for more effective management of intellectual property rights and addressing the regulatory complexity of taking a new product or process to market.

[155] See chapter 2 for a discussion of the number, nature and impact of previous reports and reviews.

Because of the complexity of the innovation process, some recommendations could be located under more than one theme. To illustrate, recommendations regarding the primary national funding bodies, the ARC and the NHMRC, could be included under Funding or Collaboration. I choose to discuss the amount of financial support under Funding, and the management of the funding by the ARC and NHMRC under Collaboration.

For each recommendation, I identify basic features inspired by a taxonomy of science and innovation policy instruments presented at the 2016 Eu-SPRI[156] conference by Abdullah Gök.[157]

I use these features as follows:

- ***Rationale*** summarises *why* I make the recommendation. It states the problem being addressed.
- ***Objective*** refers to *what* the recommendation's aims are in more detail. Some objectives fit with more than one recommendation.
- ***Target group*** refers to *who* is involved in implementing the recommendation.
- ***Discussion*** puts the recommendation in context and discusses *how* it could be implemented.

The full list of recommendations is in Figure 7.

Recommendations

CONTINUITY: "We need to take a systemic approach [to innovation] at the political level" (Participant 20)

Recommendation 1: Establish a stable, integrated National Innovation System which links together the nation's

Figure 7: Recommendations

[156] The European Forum for Studies of Policies for Research and Innovation was held 8-10 June 2016 in Lund, Sweden.

[157] The basic features include Objective, Modality and Target group. To the list, I add Rationale, and replace the word Modality with the word Discussion (Gök, Li, Cunningham, Edler, & Laredo, 2016).

Continuity: "We need to take a systemic approach [to innovation] at the political level" (Participant 20)

Throughout this thesis, I have noted that Australia's innovation system developed in an ad hoc manner, producing a fragmented, ever-changing, and poorly coordinated approach to science and innovation. The November 2015 report from The Australian Council of Learned Academies (ACOLA) agrees. It concludes: "Our review shows how our policies and supportive programs are piecemeal, opportunistic and almost invariably short-lived" (ACOLA, 2015).

The Australian Industry Group (AIG) reaches a similar conclusion. Writing in the introduction to a report by the Group, Chief Executive Innes Willox said, "…government needs to lead by holding steady: building continuity and stability in innovation policy, rather than the regular upheaval of the last two decades". And referring to the multiple reviews and reports written in since 2000, Melbourne University's Nicholas Reece stated, "Despite all the reports, there has been precious little action and an embarrassing lack of coherence in Australia's policy settings" (Reece, 2015).

The findings of my study add to the understanding of this issue reflected in these reports. Participants in my case study describe their first-hand experiences of promising research and innovation projects that falter when the funding runs out or when a change in government leads to the cancellation of a program. They describe losing colleagues and IP to places overseas where there is more continuity. Participants in my case study believe this lack of coherence -- the policy and program churn -- poses a significant barrier to their ability to maximize the fundamental and/or applied outcomes of their work. For them continuity, specifically lack thereof, is a serious constraint.[158]

Because the dynamics of the political cycle initiate much of the disruptive chopping-and-changing identified by participants, it is important to remove science and innovation policy from the political cycle where possible. As Snow Barlow of

[158] See Chapter 8, *Findings: Structural Barriers: Politics & Funding*.

Melbourne University said at a symposium in 2014,[159] "We can't wobble from electoral cycle to electoral cycle".

One way to reduce the impact of frequent political interference is to establish a non-partisan, stable innovation system which promotes continuity. As Participant 20 said, "We need to take a systematic approach [to innovation] at the political level".

The nation also needs a strategy – a plan, a vision, a roadmap – to fit within the innovation system. Without a strategy, politicians and policy makers are more likely to respond to political and national challenges with quickly-shaped, short-term solutions, lacking intellectual and historical depth.[160]

It is impossible to wave a magic policy wand and have problems vanish and solutions appear instantly. Still, I suggest that adoption at the political level of the following recommendation is a productive first step, one likely to be accepted by competing political parties given the significant role science and innovation plays – and will continue to play – in the social and economic wellbeing of the nation.

Like all the recommendations in this chapter, it is grounded in my analysis of participant data and focuses on the barriers to innovation observed by participants. However, insights from the participant data are contextualized into the broader literature on innovation policy, including reports, reviews and academic sources.

Recommendation 1 (Continuity): Establish an independent agency responsible for developing and overseeing a national strategy for science and innovation in Australia. This agency would link together the nation's political, academic and industry sectors

Rationale

Establishment of such an agency would enhance the nation's ability to build new knowledge and take ideas and discoveries from the laboratory to the market place. Such

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[159] The Melbourne Veski Symposium 21 May 2014.

[160] During his five years as Australia's Chief Scientist, Ian Chub frequently argued that Australia needs such a strategy. "Australia is now the only OECD country that does not have a contemporary national science and technology, or innovation strategy," he said in a 2014 lecture (Chubb, 2014).

a system would reduce the likelihood of politically-driven change, boost continuity and promote the adoption of evidence-based[161] policy decisions by Parliamentarians.

Objectives

1. Reduce the disruptive changes to science and innovation policies, priorities and administrative structures triggered by the political cycle.
2. Enhance the quality and continuity of long-term planning and evidence-based policy formation within government.
3. Provide an intellectual and policy framework for building the integrated programs and critical infrastructure needed to implement solutions to identified barriers such as those addressed later in this chapter: funding, collaboration and translation.
4. Stabilise planning processes at the academic and industry levels to facilitate effective administration and program formation.

Target group

This recommendation requires implementation by politicians. Establishment of an independent oversight agency which links together the nation's political, academic and industry sectors into a stable innovation system requires bipartisan support. The recommended agency should be established through legislation to provide some guarantee of continuity. Legislation would avoid disruptive changes to relevant elements of the agency, triggered by short term budgetary or political reasons.[162]

Discussion

Numerous international reports, reviews and academic papers point to specific national innovation systems which have proven successful globally. Further, scholars have analysed such systems and suggested how Australia could adapt them to its specific needs. Relevant examples include a comparison of experiences from Finland, Sweden

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[161] I follow Melbourne University's Paul H. Jensen's use of the phrase evidence-based policy: "The ultimate objective of 'evidence-based' policy is to use actual evidence on what works – rather than rely on ideology – to promote good public policies" (Jensen, 2013, p. 3).

[162] To illustrate, in December 2014 the Abbott government acknowledged it would shut down 175 federal agencies and bodies to cut costs (Crowe, 2014).

and Australia, as well as an assessment of Finland's national innovation structure[163] (ACOLA, 2015; Group of Eight, 2012; Roos & Gupta, 2004).

A common feature of these systems is an independent advisory agency, responsible for developing the overall policy and priorities of what ACOLA calls "a stable national innovation strategy". The agency links directly to the government which implements accepted advice and recommendations via government funding agencies, research centres and universities (ACOLA 2015, p. 15).

I agree with Roos and Gupta (2004) that an Australian body must be "more than just a bureaucratic think-tank". Such a strategy must have stable priority and policy building blocks, and a whole-of-government agenda, linking the many political arms of the innovation system. Most broadly, it should "address the structural and strategic barriers that inhibit innovation" (ACOLA, 2015, p. 15; Chief Scientist of Australia, 2014a, p. 3; Green, 2015, p. ix).

The agency would have responsibility for activities such as conducting foresight investigations, setting national science and industry development priorities, and promoting collaboration across the system. It would develop and oversee policies designed to engage industry in research and commercialisation of knowledge and potential products, as well as supporting public interest and fundamental research (Green, 2015, pp. 1–2; Group of Eight, 2012, p. 10; Korea Institute of S&T Evaluation and Planning, 2015; Lehto, interview, 21 June 2014; Roos & Gupta, 2004, pp. 61, 94).

Regular evaluation is a key feature of successful innovation systems. As Dodgson notes, regular evaluation of policies, programs and priorities established under the independent agency would also help reduce policy churn: "Better analysis would protect us from the periodic magic bullets discovered by politicians and pundits, with their simplistic prescriptions that we need more entrepreneurs, or more venture capital, or more collaboration" (Dodgson, 2016). Where possible, evaluation should be conducted by the same bodies or panels over time, to provide comparability of assessment through time (ACOLA, 2015, p. 20).

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[163] A 2015 report by ACOLA, *Translating Research for Economic and Social Benefits: Country Comparisons,* identifies the similarities and differences to Australia of international innovation systems (see p. 25).

As part of its 2015 National Innovation and Science Agenda (NISA), the Turnbull government announced the formation of Innovation and Science Australia (ISA). The body is responsible for researching, planning, and advising the Government on science, research and innovation matters. With bipartisan support ISA could serve as the seed for the type of agency envisioned in recommendation 1.

ISA is also well positioned review the literature on international innovation systems, consult with stakeholders, from universities to industry, and recommend ways to take on the role of an independent agency empowered to develop and oversee a national strategy for science and innovation in Australia (ACOLA, 2015, p. 12; Green, 2015, p. 1).

As I write, ISA is devising a rolling 15-year National Innovation and Science Strategic Plan. “This will identify investment priorities and specific areas for policy reform for the government to consider,” said ISA chair Bill Ferris in a speech to the European and Australian Business Council (Ferris 2016). The body could expand the scope of its work to include the objectives stated above. Alternatively, a specially created commission or the Office of the Chief Scientist could lead a public discussion and draft a truly bipartisan strategy.

Funding: “More money <laughs> at all levels” (Participant 5)

At first glance Australia’s financial commitment to science and innovation looks generous. Out of 128 nations in the 2016 Global Innovation Index, the country ranks 14th in gross expenditure on research and development (R&D) by percentage of gross domestic product (GDP).[164] But compared to South Korea (4.29% GDP) and Israel (4.11% GDP) Australia’s commitment of 2.2% GDP pales. Other innovative nations – Japan, Finland, Sweden, Denmark and Austria – spend over 3% GDP on R&D. And Australia invests less of its GDP on R&D than Switzerland, Germany, the USA, Belgium and France.[165]

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[164] See https://www.globalinnovationindex.org/gii-2016-report#). The GII tally of R&D expenditure includes the conception or creation of new knowledge, products, processes, methods, or systems across all sectors of the economy, not just in areas normally associated with science and technology products and services.

[165] Ibid

The GII data also indicates that Australian business contributes less than comparable nations in terms of the percentage of GDP it allocates to R&D. At 1.24% GDP, Australian business ranks 15th, behind the same suite of leaders. Again, South Korea (3.36% GDP) and Israel (3.47% GDP) are the world leaders, this time with the highest level of business expenditure on R&D.[166]

In dollar terms, the Commonwealth's 2016-2017 budget tables, released 18 August 2016, indicate the government plans to spend $10.1 billion on science, research and innovation.[167] However, as Dodgson notes, Commonwealth spending on R&D declined by 20% as a share of GDP over the last 20 years, this despite the resources boom (Dodgson, 2015a).

In sum, and as discussed in Chapter 2, Australia's overall contribution to science and innovation is slim compared to the most successful nations noted above. Taken together, the international and national data strongly support Participant 5's call for "More money".

If the country wants to transition to a so-called knowledge economy -- and associated high-skill, high-wage jobs -- from its previous economic reliance upon the resources sector, it must boost investment in science and innovation in line with other developed nations. Australia's global competitors continue to invest in science, despite more challenging financial and economic circumstances (AAS, 2013, p. 3).

Recommendations in this section, therefore, focus on the quantum, placement and maximisation of funding for science and innovation. All my recommendations call for actions by the Commonwealth, as this is the most direct way to boost innovation funding in the near and long-term. Reflecting the fact that few of my interviewees had industry experience, my recommendations target the public sector. Further work on system-based policy measures to directly encourage increased business investment in R&D would add significantly to my recommendation mix.[168]

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166 Ibid

167 See https://industry.gov.au/innovation/reportsandstudies/Pages/SRIBudget.aspx.

168 I continue numbering recommendations sequentially, rather than doing so separately for each section.

Recommendation 2 (Funding): Increase the Commonwealth budget for science and innovation to a minimum of 3% GDP

Rationale

Based upon international comparisons of comparable nations, Australia's innovation system is under-funded. The system must be supported more generously if the nation wants to maximise the benefits of its R&D effort and be globally competitive.

Objectives

1. Provide funding for policies and programs developed under the National Strategy discussed under Recommendation 1.
2. Support training for researchers and industry players to improve their ability to work collaboratively.
3. Fund industry experience for early and mid-career (EMC) researchers to increase their job mobility and broaden their career paths in Australia.
4. Stimulate private sector input into R&D and commercialisation.

Target group

This recommendation requires implementation by politicians. As with all major funding decisions made by the Commonwealth, an increase in the volume of support for science and innovation begins as a so-called line item in the government's annual budget. The budget is debated by Parliament which may, or may not, pass the budget legislation. Bipartisan support is, therefore, essential for increased, ongoing support for R&D and commercialisation of research.

Discussion

Given that Australia is not keeping up with the leaders, it risks falling further behind. The scientific community agrees investment must rise if the nation is to maintain its quality of life and economic competitiveness. Yet no nation has an unlimited ability to fund its scientific community. Decisions must be made about the quantum of support for science and innovation – what is desirable and what is achievable.

Scientists in leadership positions have considered the issue. While it may seem an arbitrary figure, many recommend that the Commonwealth invest at least 3% of GDP in science and innovation. Reece puts a 3% target in context: "By comparison, South Korea has a target of 5 percent" (Field & Holmes, 2016; Reece, 2015).

Lifting Australian investment in R&D from 2.1% GDP to 3% GDP was also recommended by the 2015 Senate Economics References Committee (p. ix) review of Australia's innovation system, and reiterated by Green in his supplementary report to the review. The figure of 3% is part of a recommendation calling for a "more stable, coherent and effective administrative arrangements, a long-term time horizon and a budgeting and resource allocation that is fit for purpose" (Green, 2015, p. 1).

Achieving a minimum expenditure of 3% GDP increase would require an additional $5 billion[169] a year of public funding in the annual science and innovation budget. This figure is a starting point for a comprehensive review of the Commonwealth's financial commitment to science and innovation (Field & Holmes, 2016).

The Productivity Commission is the Australian Government's independent research and advisory body on a range of economic, social and environmental issues affecting the welfare of Australians. One of its functions is conducting public inquiries and research studies.[170] Although it is known for its 'dry' economic stance, I suggest the Commission work in conjunction with ISA to review the existing literature, consult with stakeholders, and develop a recommendation regarding a funding increase for science and innovation. The resulting document would be viewed as rigorous across the political divide and could, therefore, persuasively include a call for stable funding from government to government.

Convincing the government of the day that an increase is necessary and affordable will not be "an easy task and not something that will happen quickly" (Field & Holmes, 2016). That is so because, as discussed in Chapters 2 and 7, governments tend to see science and innovation as a place to cut funding. They also prefer short-term project funding, allowing them to make frequent public announcements about their activities.

Still, as with the previous recommendation, I argue that with persistent and on-going representation from the scientific community and informed economic and policy

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[169] In his piece with Webster, Green states that "budgets are about priorities" and suggests that $5 billion could be found for science and innovation funding by winding back the annual diesel fuel tax rebate (Green & Webster, 2016).

[170] See http://www.pc.gov.au/about

experts, a strong case can be made. Further, the largely bipartisan backing for the National Science and Innovation Agenda (NISA), discussed in Chapter 2, suggests potential support across Parliament.

A case study of a single project such as the bionic eye initiative cannot give a clear sense of whether funding is adequate for research and development overall. However, participants' accounts of practices such as universities using project grant funding to provide infrastructure for routine research by continuing academic staff suggest chronic shortfalls. What came even more clearly out of the findings of the case study were concerns about the administration of targeted funding. Recommendations 3 and 4 in this section suggest ways in which a boost to overall science funding could be used to target funding issues which directly affect the university sector.

Recommendation 3 (Funding): Provide consistent support to the ARC & NHMRC at a level reflecting the overall increase to science & innovation funding outlined in Recommendation 2

Rationale

Australia's primary research funding bodies are the ARC and NHMRC. The amount of competitive funding available to them varies yearly with the annual federal budget. So too do the number and type of grants available from both councils. Increasing and stabilising funding would enhance research and innovation outcomes by supporting more high-quality projects and encouraging researchers to explore promising, but unfunded, areas of research (Chubin & Hackett, 1990, pp. 60–65).

Objectives

1. Increase the number of longer-term and follow-on projects where appropriate. Not all worthwhile projects can be completed within a grant period.
2. Increase and retain the scientific talent pool by providing more opportunities for EMC researchers who rely heavily on post-doctorate grants to build a career.
3. Encourage the return of senior Australian-trained scientists by offering well-funded research projects.

Target group

Like recommendation 2, this recommendation requires implementation by politicians. They determine the amount of funding available from the annual Commonwealth budget to the ARC and NHMRC. Bipartisan support will be needed to ensure funding to the agencies is boosted and stabilised.

Discussion

Participants across the innovation system felt that federal support for the ARC and NHMRC is highly variable, intensifying the impacts of what they see as inadequate funding to the bodies. There are serious consequences, they say, for the scientific workforce, and, therefore, its ability to conduct high-quality research. There is evidence for their concern.

Firstly, the total amount of funding available to the ARC and NHMRC varies yearly with the annual federal budget. The 2016-2017 budget, to illustrate, cut funding to the ARC by 9%, compared to the previous budget. The result is that competition for funding is intense, and every year many more applications are rejected than supported (AAS, 2013, p. 4; Green & Webster, 2016).

Discussing funding for the NHMRC in a pre-budget submission to the federal government, the Australian Society for Medical Research (ASMR) argued "incontestable data" support the claim that the health and medical workforce is "at serious risk" from inadequate support. The NHMRC contributes to over 70% of health and medical research workforce salaries. Among the other statistics cited by the ASMR:

- A 16% loss of researchers from the major NHMRC funding scheme (Project Grants) in the previous 3 years.
- A 25% drop in the number of researchers in the leadership tier of the NHMRC Fellowship Scheme since 2011.
- 25% of the workforce are uncertain about their likely employment in the next calendar year (ASMR, 2016b).

Additional statistics from an ASMR workforce survey, released in 2016, reveal that 83% of respondents considered leaving active research for another career option. The majority of those respondents are mid-career researchers, that is 6-15 years postdoctoral. Further, 61% of respondents considered leaving Australia for a period of three years or permanently (ASMR, 2016a, pp. 6, 8).

Those statistics are echoed by the results of the *Australia Postdoctoral Reference Survey*, reported in 2016 by the EMC Researcher Forum (EMCRF). Nearly 63% of respondents believe Australian researchers must have overseas experience to be competitive at home, and 55% considered moving overseas. The survey also showed that respondents feel they live in a "Postdocalypse" in which EMC jobs in government, academia, and industry are poorly paid and insecure (Hardy, Carter, & Bowden, 2016, pp. 2–3).

Cancer researcher Geoffrey Matthews summed up the need for enhanced, stable funding to the ARC and NHMRC:

> I had always believed that contemporary Australian scientists did not need to head overseas to pursue a career due to the high-calibre research being carried out in our institutions. However, without the availability of sufficient funding to fund our research we are being driven overseas...In my case, and my wife's, an early-career researcher in paediatric neuroscience, we chose the United States. (Dunlevy, 2016)

In order to advance Recommendation 3, I argue that additional funding from Recommendation 2 should flow through to the Australia's funding bodies, particularly the ARC and NHMRC.

The Office of the Chief Scientist or ISA could coordinate representations to that end from stakeholders such as the ARC and NHMRC, the AAS, the Australian Academy of Technology and Engineering, and the EMCRF. The representations should be made to the Minister responsible for science and innovation, along with other politicians with responsibility for portfolios linked to scientific and technical advances, say defence, industry, communications, health and environment.

Because science and innovation are not a government's top priority, representations should also be made to the federal opposition with the document, along with other parliamentarians and the media. This could help build a more bipartisan approach to the recommendation and encourage the government to support it in its annual budget.

Recommendation 4 (Funding): Increase Research Block Grant support to cover the equivalent of at least 50 cents for every dollar of competitive research grant support awarded.

Rationale

Australia's current funding system of competitive research grants does not cover the full cost of university research. Increased support for Research Block Grants (RBGs)[171] awarded to academic institutions would increase fundamental and applied research outcomes from the university sector and, therefore, help meet the goals of the national strategy discussed in Recommendation 1.

Objectives

1. Enhance the ability of universities to cover the indirect costs of research funded through competitive grants without heavy reliance on general university funds.
2. Enable universities to make strategic decisions about research investments in areas beyond researcher-driven competitive grants.

Target group

This recommendation requires implementation by politicians. Funding for a RBG increase must come from the annual federal budget. The minister, or ministers, with responsibility for science and education should have significant input into creation of budget items relevant to the recommendation. Again, bipartisan support is required to help ensure passage of the budget legislation by Parliament.

Discussion

Under Australia's dual funding system for research, competitive grant schemes such as those managed by the ARC and NHMRC support only the direct costs of individual research projects. The RBG scheme is intended to help universities cover the indirect costs of research such as maintaining laboratories, research infrastructure and lead

[171] The Australian Government operates a dual support system for funding of research and research training. The system consists of (1) performance-related block grants, which are allocated to universities based on performance metrics, along with (2) competitive grant programs administered primarily by the ARC & NHMRC. As of 2017, the RBG system was simplified (see https://industry.gov.au/innovation/InnovationPolicy/Documents/NISAnnex6.pdf; and https://www.education.gov.au/research-block-grants).

researcher salaries. In theory, RBG funding provides the necessary flexibility for institutions to foster new areas of research, train students, and make strategic decisions about their research investments (Universities Australia, 2015, p. 6; Watt, 2015, p. 11).

Until December 2016, the RBG scheme contained six programs. Each program was funded from a separate pool of funds in the federal budget, and each had restrictions about how the funds could be used. That changed in May 2016 when the government accepted all recommendations of the 2015 *Review of Research Policy and Funding Arrangements*, headed by Ian Watt[172] (Birmingham, 2016; Department of Education and Training, 2016; Jensen & Webster, 2016, p. 186; Pettigrew, 2015, p. 2).

Initial changes to the RBG scheme began in January 2017. Today, the scheme has two arms, the Research Support (RS) program and the Research Training (RT) program. Grants for the RS program are awarded to universities based on a funding formula which includes two equally weighted criteria: 1) the level of competitive grant funding, and 2) income from business and end users.[173] The funding formula for the RT program gives equal weight to higher degree research student completions and research income from all sources[174] (Watt, 2015, p. ii).

Regardless of the restructuring and the addition of $180.2 million, over four years, to boost the RS program, the reality is that the indirect costs of university research are not fully covered. The Allen Consulting Group estimated in 2009 that the average indirect cost was 85c/dollar of grant funding. Yet the amount provided through the RBG to support indirect costs has remained below 25c/competitive dollar since 2009, despite stated government intentions to increase support to 50c/dollar (Allen Consulting Group, 2009, p. 54; Department of Education and Training, personal communication, 6 February 2017; Universities Australia, 2015, pp. 6–7; Watt, 2015, pp. 13–14).

To compensate, universities fund the gap between their RBG allocation and the full indirect research costs from general funding, relying primarily upon international and

[172] https://docs.education.gov.au/node/38976.

[173] See https://www.education.gov.au/research-support-program

[174] See https://www.education.gov.au/research-training-program

domestic student fees, with smaller contributions such as non-research specific donations and bequests and investment income[175] (Universities Australia, 2015, p. 7).

In order to reduce the impact on universities of high indirect costs, I suggest an increase to the equivalent of at least 50 cents for every dollar of competitive research grant support. I say "the equivalent of at least 50 cents" because since the changes to the RBG scheme, it is not possible to calculate the rate of funding for indirect costs using the existing formula (Department of Education and Training Media, personal communication, 6 February 2017; Universities Australia, personal communication, 24 February 2017).

I suggest the Department of Education and Training work with Universities Australia to devise a new method for calculating the funding shortfall for the full cost of research. As well, I suggest that the Chief Scientist or the AAS oversee preparation of recommendations to government regarding enhanced funding for the RBG scheme. Once a document is finalised it should be presented to the ministers with responsibility for education, science and technology.

Efforts should also be made to familiarise the federal opposition with the document, along with other Parliamentarians, peak university and academic organisations, and the media. Broad support from stakeholders would lend weight to the recommendations and encourage the government to increase in the RBG scheme to cover indirect costs from the overall increase to science and innovation funding as per Recommendation 2. Such support would also increase the likelihood of continued support after a change in government.

Recommendation 5 (Funding): Establish a government funded pre-commercial procurement program to drive private sector R&D

Rationale

An adequately funded pre-commercial procurement program would stimulate R&D activity in the private sector and encourage the investment of venture capital, while meeting government needs for science and technology-based products and services.

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[175] Clearly, 'minding the gap' from general funding channels university funds towards disciplines with high indirect costs such as the sciences, and away from those with lower costs such as those in the liberal arts. Research intensive institutions are most heavily impacted (Universities Australia, 2015, p. 7; Watt, 2015, p. 12).

Objectives

1. Encourage private sector investment in young science and technology based companies by reducing the perceived risk of investing in new products and processes.
2. Meet government needs for products or services that are not commercially available.
3. Help create a public market for new products or services by demonstrating their use and value in a real-world context.
4. Provide government access to potential income from the development of products or services through contractual arrangements regarding the eventual sale of patents or the products or services.

Target group

As with the preceding recommendations, a pre-commercial procurement program requires implementation by politicians. Similarly, support for such a program must be provided through the federal government's annual budget process. It would come from funding not covered by the 3% increase suggested in Recommendation 3. Efforts should be made to gain support from opposition Parliamentarians, as well as government politicians and ministers to build widespread support for the measure.

Discussion

In Chapter 8, Participant 3 led the discussion of funding with the comment, "We don't have enough money". I have offered the earlier recommendations, calling on the Commonwealth government to provide greater financial support to publicly-funded research and the ARC and NHMRC which manage much of the research dollar.

But it is not just the responsibility of government to support innovation in Australia. As Webster says, "We know that just funding public sector science isn't enough". The private sector must contribute. Nonetheless, as participants claim, industry is risk averse. I noted above that OECD statistics support that view (Webster, 2015).

Efforts by successive governments to encourage private investment in R&D and translation rely heavily on indirect support for business R&D through tax measures such as the R&D Tax Incentive (ACOLA, 2015, p. 17). In 2016, Bill Ferris, Chief Scientist

Alan Finkel and Treasury Secretary John Fraser conducted a review[176] of the effectiveness and administration of the incentive. Writing about their review in *The Australian Financial Review* they said:

> The Australian government invests about $10 billion each year in programs for research, science and innovation that are vital to our future prosperity. The R&D Tax Incentive accounts for roughly 30 per cent of the total allocations, which in turn is over 90 per cent of government support for business R&D. (Ferris, Finkel & Fraser, 2016)

The trio's conclusion that "the R&D Tax incentive is, and should remain, an important investment" is well considered, as are the review's specific recommendations about improvements to the scheme. By mid-2017, the government has taken no action on the six recommendations made by Ferris, Finkel and Fraser (2016), but is expected to respond later in the year.[177]

There are, nevertheless, other potentially effective strategies for boosting private sector investment in R&D. Among these, pre-commercial procurement programs have been adopted in many nations. They aim to encourage small to medium-sized enterprises (SMEs) to engage in market-oriented R&D by supporting the development of products and services not commercially available but required by the government (Green, 2015, pp. 36–37). Such programs have been found to stimulate innovation "existing structures" and to "catalyse" industry to engage in new areas of activity (Rothwell, 1994, pg 629).

One of the longest running, and best-known examples of the pre-commercial procurement undertaken by governments is the Small Business Innovation Research (SBIR) program of the US. A variant of the program was adopted by the UK as its Small Business Research Initiative (SBRI)[178] (Chubb, 2016; Rigby, 2016, p. 384).

The SBIR program, "America's Seed Fund",[179] was conceived in the 1970s by Roland Tibbitts, a National Science Foundation program officer with experience as an executive

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[176] See https://www.business.gov.au/assistance/research-and-development-tax-incentive/review-of-the-randd-tax-incentive.

[177] See http://minister.industry.gov.au/ministers/hunt/media-releases/rd-tax-incentive-review-report-released-consultation.

[178] For details see https://sbri.innovateuk.org/.

[179] See https://www.sbir.gov/.

with two high-tech companies. He realised the private sector -- especially at the SME level -- was reluctant to invest in R&D, while at the same time the government had significant need for new products and processes to run its increasingly diverse departments and projects (Chubb, 2016).

Initiated with bipartisan support by the Reagan administration in 1982, the program requires all US agencies with an R&D budget above US$100 million to devote a set percentage of their total funding to SBIR. The agencies call for proposals relevant to their individual needs and pick the best for next stage funding. They work with selected companies to take the technology to the point of roll-out within government, launch on the market or both. To date, the SBIR program has resulted in roughly US$41 billion in venture capital investments, 70,000 issued patents, and the establishment of nearly 700 public companies[180] (Chubb, 2016).

Australian governments have, and are, procuring pre-commercial products and services from industry. For example, pre-procurement is being used by the Defence Science and Technology Group in research fields such as cyber security, weapons systems, and air, land and sea vehicles.[181] Overall, however, the nation's approach is scatter gun and lacks continuity (Zelinsky, 2016). In contrast, an SBIR style program provides a "structured approach and support" for a government's procurement process for science and technology-based products and processes (Witty, 2013, p. 128).

Establishment of such a program was recommended in *Australia's Innovation Future*, the consultant's report to the 2015 Economic References Committee review of the innovation system. In response, a pilot program, the Business Research and Innovation Initiative (BRII),[182] was launched in August 2016 and given a budget of $19 million. It will run for three years as part of the NISA (Chubb, 2016; Green, 2015, pp. 36–37).

It is worth noting that in July 2016, the Queensland government launched a small $5 million SBIR pilot program, set to run for four years.[183] Instead of a government agency

[180] See https://www.sbir.gov/birth-and-history-of-the-sbir-program.

[181] See https://www.dst.defence.gov.au/our-science for a list of research areas in which pre-commercial procurement is employed.

[182] See http://www.innovation.gov.au/page/business-research-and-innovation-initiative.

[183] See http://statements.qld.gov.au/Statement/2016/7/17/5-million-funding-for-smes-to-win-major-government-contracts and http://advance.qld.gov.au/small-business/sbir.aspx.

going to the market for a specific product or service, industry or research applicants propose solutions to "challenges" set by the agency. Suitable applicants are funded to test their solution's technical and commercial viability. If the outcome is promising, support is offered to develop pre-commercial prototypes which may be procured by the agency. (Queensland Department of Science, Information Technology and Innovation, personal communication, 2 March 2017).

With two pilot projects underway, both NISA's BRII and Queensland's DSITI will obtain valuable Australian data on which to assess the viability of such projects. Useful ideas and lessons could be shared to mutual benefit. Further, the data could be used to build recommendations to both levels of government regarding the establishment of permanent SBIR style procurement programs. Recommendations should be delivered to the appropriate ministers, with efforts to obtain support as whole-of-government initiatives.

It should be noted that the bionic eye initiative, despite strong government backing, would not have been a candidate for pre-procurement because the government does not directly procure medical devices. Furthermore, medical device procurement is complex due to the need for clinical trials and regulatory approval from the Therapeutic Goods Administration (TGA) to confirm that the device is safe.

It is, nevertheless, worth considering what steps government could take in the context of medical devices and treatments to create confidence that there will be a market for successful innovations. In Australia, one tool the government has is the prosthesis list,[184] a list of medical devices that are entitled for Medicare rebates and for which private health insurers must pay benefits. If the government is serious about an initiative such as the bionic eye, they can give confidence to prospective commercial partners by indicating that the product will be added to the prosthesis list if it meets some standard/criteria and secures TGA approval.

[184] See http://www.health.gov.au/internet/main/publishing.nsf/content/health-privatehealth-prostheseslist.htm.

Collaboration: "Collaboration is the buzz word of the 2000s" (Participant 7)

According to the Macquarie Dictionary, a buzz word is a "jargon word used for its emotive value or its ability to impress the listener" (3rd ed, 1997, p. 303). Regardless of the intent, the word 'collaboration', as Participant 7 suggests, is getting a workout in science circles. A February 2017 search on Google Scholar listed 32,700 papers on 'scientific collaboration' for 2016. It returned another 4,300 listings for January to February 2017.

For my purposes, I follow the straight-forward definition of collaboration offered by New South Wales Chief Scientist & Engineer Mary O'Kane in a 2008 review of Australia's Cooperative Research Centres program. "Collaboration is an interactive process that involves two or more people or organisations working cooperatively towards a common goal." She adds that collaboration serves, potentially, to benefit all parties, possibly including third parties. In a successful collaboration, the "joint inputs" lead to "joint outputs" which are greater than the participants could accomplish on their own (O'Kane, 2008, p. 3).

Echoing this definition, the Australian Industry Group's 2016 report *Joining Forces* says the importance of collaboration in the innovation process is "widely acknowledged". The potential benefits to participants – both within the research community and between researchers and industry -- are also discussed frequently by industry and academic players (AIG, 2016, p. 18).

The importance of including industry partners in these teams is not always appreciated by researchers and industry personnel alike. After all, as participants claim, the academic and private sectors have fundamentally different goals and ways of working. Still, as Green says, the most "transformative" advances occur at the public-private boundary. That is where novel ideas become new-to-the-world advances and products (Green, 2015, p. 1).

When the sectors agree to collaborate, a well organised partnership can enhance the innovation process in many ways. The questions asked can be broadened beyond the purview of academics, often with limited commercial experience. Collaboration also helps break down intellectual and professional silos, and widens networks. Knowledge, ideas and resources flow. Potentially viable products or processes may more quickly make it to market with the application of a wider mix of expertise and equipment (AIG, 2016, p. 18; Jensen & Webster, 2016, p. 185; O'Kane, 2008, p. xi).

Still, collaboration should not become an end in itself. After all, it can be risky. As many of my participants noted, a productive collaboration is neither easy to achieve nor sustain. Between 50% and 75% of all interorganisational collaborations fail (Keast & Charles, 2016).

The difficulty of maintaining a creative collaboration is illustrated by the revised history of the bionic eye initiative, outlined in Chapter 5. While many factors beyond failed collaboration affected Bionic Vision Australia – for instance the tyranny of distance and the shortage of people with project management experience – poor collaboration hampered the consortium's productivity.

More broadly, and as I discussed in earlier chapters, Australia has a poor record of academic-industry collaboration. This has changed little over time. Research-based industries were collaborating no more with universities in 2012 than they were in 2005. And today, Australia ranks last out of 26 OECD countries on the proportion of businesses collaborating with public research groups on innovative activity (Office of the Chief Economist, 2015, p. 115; Watt, 2015, p. i).

The 2016 AIG survey of industry leaders confirms the statistics, finding that the private sector remains reluctant to collaborate with universities. The report concludes that Australia's weak levels of such collaboration "are a serious problem". For example, the group blames poor collaboration for the fact that less than 1% of new-to-the-world products are developed in Australia (AIG, 2016, p. 18).

Scholarly investigation supports my conclusion, based on participant interviews, that there is a cultural divide, a culture clash, which helps explain the reluctance by both the academic and industry sectors to collaborate with one another. Again, the two cultures have different goals and different expectations about how to work with others. As participants observed, communication and cooperation can be poor within multidisciplinary academic research, let alone in university-industry collaborations (Cunningham & Gök, 2016, p. 240; Green, 2015, p. 9; Shepherd, 2014, p. 16).

Government intervention plays an important role in a nation's innovation system. I agree with experts who argue that it is the role of governments to go beyond merely correcting market failure. In terms of collaboration, governments have a significant obligation to develop public policy designed to facilitate academic-industry cooperation, especially in areas of national importance (Cunningham & Gök, 2016, pp. 242–243; Green, 2015, p. 1; Shepherd, 2014, p. 16).

Further, Australian governments themselves agree. Since the 1980s, Commonwealth governments of all political persuasions have actively encouraged academic-industry collaboration with mixed results. Some programs such as the ARC Centres of Excellence and the ARC Linkage Projects scheme continue, albeit with variable funding and priorities, as discussed in the Funding section of this chapter.

But although the importance of collaboration – what the AIG report calls "interconnectedness" (AIG, 2016, p. 18) – is recommended,[185] recognised and supported, there has been scant academic and policy attention given to critical factors inherent in collaboration. Green lists these as the "structures, rules, relationships, policies, systems, and processes under which collaboration between universities and industry can be developed and maintained" (Green, 2015, p. 9).

Part of the analytical shortfall derives from the difficulty of evaluating and comparing schemes and policies. As discussed in earlier chapters, programs and policies are subject to frequent change. Further, meaningful results are hard to obtain due to difficulties of defining and collecting comparable data.[186] This is, in part, why I suggested in the discussion of Recommendation 1 that it is advisable, where possible, to have programs reviewed regularly by the same independent team. Such reviews could be undertaken by the independent agency of Recommendation 1.

According to O'Kane (2008), the result of these limitations is that Australia has been running a "big, somewhat under-designed experiment" in collaboration. Schemes

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185 Most recently, the Senate Economics References Committee's review of Australia's Innovation System dealt directly with collaboration in its recommendations. The committee called for "measures to enhance collaboration and the free flow of knowledge between the university and the private sector" (Senate Economics References Committee, 2015, p. ix).

186 The challenge of reviewing collaboration programs and policies is not limited to Australia. Cunningham and Gök (2016, p. 270) note that evaluation, generally, has methodological limitations. A fundamental weakness, they say, is that the process of collaboration is often treated as a 'black box'. Consequently, it is difficult to define a set of consistent variables to assess, and, therefore, to identify what works and what doesn't in various policies and programs.

promoting collaboration come, go, interact with one another, add complexity, cost, and often incompatible governance arrangements -- with little or no demonstrated benefit (O'Kane, 2008, p. 9).

Nonetheless, it is becoming clear to international policy experts that there are typical pre-conditions for successful academic-industry collaboration. As suggested by my funding recommendations, a key pre-condition is long-term, stable government funding and support. Others include prior relationships between participants, personnel stability, geographic proximity, and shared goals. Cunningham and Gök (2016, p. 270) say such factors positively influence trust, information sharing, and coordination effectiveness, all of which are important in productive collaboration.

My collaboration recommendations reflect these pre-conditions, which also dovetail with comments about collaboration from my participants.[187] While I consider aspects of existing funding bodies such as the ARC and NHMRC, I do not make recommendations on specific programs such as the CRCs or recent schemes developed under the NISA. That is a job beyond the scope of this thesis.

Instead, as with all my recommendations, those regarding collaboration emerge from the lived experience of my participants. They add to the developing body of knowledge about collaboration, successful and otherwise. The following recommendations spotlight public-private sector networks, ARC and NHMRC funding procedures, academic metrics, leadership training, and precincts.

Recommendation 6 (Collaboration): Establish a permanently-funded commercialisation network of centres targeting late-stage R&D and commercialisation

Rationale

Borrowing from successful overseas models along the lines of the Catapult Centres in the UK or Finland's Strategic Centres for Science, Technology and Innovation, a continuously-funded network of centres where publicly-funded researchers and industry

[187] My recommendations target the government, academic & industry levels. At https://theconversation.com/ten-rules-for-successful-research-collaboration-53826 Southern Cross University's Robyn Keast and Michael Charles offer tips researchers themselves can follow to boost the success of their collaborations. They reflect barriers identified by my participants.

work together to take high-potential products and services to market would attract private sector investment, thereby boosting outputs from the nation's research effort.

Objectives

1. Encourage private sector investment in R&D with a focus on science and technology-based products and services with high commercialisation potential.
2. Create greater opportunities for industry-academia interactions, including exchange and training of researchers and experts in industry and academia without loss of career paths in their home sector. This would be particularly valuable to managers and researchers in the academic sector who have little or no industry experience, and to EMC researchers seeking to boost their ability to work in industry, as well as the academic sector.
3. Provide assistance with the complex technical and regulatory hurdles of translation across the valley of death, discussed in chapter 9.
4. Provide government, as well as industry, with access to potential income from the successful commercialisation of products or services and the use of new intellectual property.

Target group

Politicians and business leaders. As with the previous recommendations in this section, support for a permanent commercialisation network must be provided through the federal government's annual budget process. Efforts should be made to gain support from opposition Parliamentarians, as well as government politicians and ministers. Support from business leaders and the publicly-funded research community is critical.

Discussion

Not only is Australian business reluctant to invest in R&D, OECD statistics have ranked Australia at the bottom of advanced economies for collaboration between business and the academic and government-funded research sectors (AIG, 2016, p. 3). Additionally, "Very few businesses offer positions to research-trained staff" (Chubb, 2014, p. 2). Less than one in three Australian researchers work in industry in contrast to the US where four out of five researchers are in the private sector.

To encourage Australian industry to recognise the value of collaborating with public sector researchers and investing in R&D, the Commonwealth has competitive funding initiatives such as the Cooperative Research Centre (CRC) Programme[188] and ARC Linkage Projects scheme.[189] Both programs seek to bring industry and public research bodies together, reducing the risk perceived by the private sector of supporting and conducting collaborative research.

Both programs require a contribution in cash and/or in kind from the industry partner. Both, however, are research oriented. Noting a 2003 review of the CRC program, Paul Cunningham and Abdullah Gök (2016) say the focus is on "research at the expense of commercialising and utilising intellectual property". Yet research is not the job of a network seeking to commercialise late-stage R&D (Cunningham & Gök, 2016, p. 268).

Additional factors hamper the ability of the CRC Programme and ARC Linkage Projects scheme to take research from the laboratory to the marketplace. Both programs are time-limited and subject to policy changes, as well as to variable funding support. "Comparatively little funding is available to support research engagement between business, universities and research organisations" (Reece, 2015).

The federal government also sponsors the Entrepreneurs' Program,[190] along with a variety of initiatives under the umbrella of the NISA.[191] Many of the projects support private sector start-ups. The outcome of these programs has yet to be fully evaluated. They are, however, poorly linked to public sector research activity and are subject to swings in the political cycle.

After speaking to my case study participants and reviewing available documents and literature, I conclude that a network of permanently-funded centres, aimed at late-stage R&D and commercialisation of high-potential products and services could provide a more effective approach. I argue a network centre could have managed the bionic eye initiative, helping prevent some of the collaborative difficulties experienced by, in particular, the BVA consortium. Such networks could also help overcome limits of the government-sponsored programs noted above, as well as meeting the objects outlined in this section.

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188 See https://www.business.gov.au/Assistance/Cooperative-Research-Centres-Programme/Cooperative-Research-Centres-CRCs-Grants.

189 See http://www.arc.gov.au/linkage-projects.

190 See https://www.business.gov.au/assistance/entrepreneurs-programme-summary.

191 See http://www.innovation.gov.au/audience/startups-and-entrepreneurs.

Moreover, there are numerous international examples of publicly supported networks aimed at creating what the Senate Economic References Committee called a “seamless innovation pipeline” in its 2015 interim report on Australia’s Innovation System. Among the most widely recognised are the Catapult Centres in the UK, Finland’s Strategic Centres for Science, Technology and Innovation (SHOKS), and the Fraunhofer-Gesellschaft network of institutes and research facilities in Germany (Senate Economics References Committee, 2015, p. 1).

While the Fraunhofer institutes[192] conduct applied research and consulting services for private and public enterprises, the Catapult Centres, in particular, and the SHOKS more closely resemble the network I recommend. SHOKS are non-profit companies that bring together large companies, universities and research institutes to solve R&D problems in target areas such as energy and the environment. The emphasis of these publicly and privately-funded centres is commercialising ideas and meeting national goals (Lehto, interview, 21 June 2013; Group of Eight, 2012, pp. 20–21; Rae & Westlake, 2014, pp. 7–8; Shapira & Youtie, 2016, p. 169).

The Catapult Centres are a network of physical centres where businesses, from small to large, collaborate with government and academic researchers to refine and commercialise potentially valuable late-stage R&D. The centres are supported by a combination of business-funded R&D contracts, won competitively, and collaborative applied R&D projects, funded jointly by the public and private sectors, also won competitively. Core public funding maintains long-term investment in infrastructure, expertise and skills development (S. Harris, 2014, p. 18).[193]

There are currently 11 centres scattered across the UK, each focusing on different areas of commercial and national importance. Examples include cell and gene therapy, energy systems, and satellite applications. A 2014 review of the centres called for expansion, based on gradually escalating government funding, to 20 centres by 2020 and 30 by 2030 (Hauser, 2014, p. 36).

What makes the Catapult network a leading model for an Australian translation network is that it recognises the reluctance of the private sector to take on potentially risky late-stage R&D. It also acknowledges a common thread mentioned by participants—most

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192 See Research in Germany (2016).

193 See https://catapult.org.uk/about-us/about-catapult/.

researchers lack the expertise needed to navigate commercial partnerships. They need help taking ideas and prototypes across the so-called valley of death, a stage in the innovation process where many, if not most, potentially viable prototypes and processes die due to a lack of private investment.

The Catapult network seeks to provide just such training for researchers and industry players. It also offers scientific infrastructure, and expert advice with the technicalities of translation, from intellectual property to regulatory hurdles.

The Catapult concept should be modified for Australia. As an independent body "responsible for researching, planning, and advising the Government on all science, research and innovation matters", ISA is well suited to take the lead on the task of devising a permanently funded commercialisation program targeting late-stage research and development.

The ISA recommendation should be delivered to the appropriate minister, currently the Minister for Industry, innovation and Science. ISA should work with academic scientists, government researchers and industry stakeholders to bring the recommendation to the attention of the Parliament, as well as the full cabinet of government. Likewise, the goal would be to obtain bipartisan support for passage of a bill to enact the recommendation.

Recommendation 7 (Collaboration): Revise procedures used by the ARC and NHMRC to evaluate and monitor competitive grant applications to reflect a more efficient, fit-for-purpose approach

Rationale

Reducing the burden on researchers, universities and partner organisations of the grant application process would boost time spent on productive, rather than administrative, collaboration. That, in turn, would increase the likelihood that viable products and processes are commercialised.

Objectives

1. Reduce the time and cost expended by researchers, universities and partner organisations on preparing grant applications, many of which will not be supported due to funding or policy constraints, rather than questions of quality.

2. Reduce the amount of time spent by team leaders on ongoing administration of successful proposals. Time devoted to these tasks takes them away from hands-on work in the laboratory, along with teaching and managing group members. This is critical in projects unable to afford a dedicated manager.
3. Lower the administrative costs spent by funding bodies on evaluating and monitoring the grant process.
4. Reduce strategic collaboration in which team leaders select project partners on their likely appeal to funding review committees, rather than the needs of the proposed project.

Target group

While the ultimate responsibility for developing, trialling and implementing restructured policies for managing the funding process lies with the ARC and NHMRC, to be truly effective the government of the day must support the process in principle, if not with financial support.

Discussion

In 2012, Australian scientists collectively spent more than five centuries' worth of working time preparing research-grant proposals for the NHMRC, the nation's largest funding scheme. Of the 3727 proposals submitted, 3570 were reviewed, and 731 – or 21%[194]- were funded. Danielle Herbert and her Queensland University of Technology and Melbourne University colleagues estimated that the 550 working years of researchers' time was equivalent to salary costs of $66 million -- most of which was expended for no immediate benefit due to a failure to obtain funding (Herbert et al. , 2013b, p. 1).

Writing in *Nature* about their work, Herbert's team noted: "The system needs reforming and alternative funding processes should be investigated" (Herbert et al., 2013a). Or as

194 The most recent evidence is that 20-30% of applications deemed 'fundable' by ARC and NHMRC peer reviewers are funded. Roughly 50% of received applications are determined to be 'not fundable'. Critically, in 2016 the success rate of the NHMRC Project Grants scheme dropped to just 14% from 23-24% in 2010 (AAS, personal communication, 6 Jan 2017; Willis, interview, 3 March 2017).

the former head of the California Institute for Regenerative Medicine, Alan Trounson,[195] said in 2014, "The grant application system is broken".

To reiterate, the most significant funding bodies are the ARC and the NHMRC. Through competitive grants they support both fundamental and applied research. Clearly, not all the grant schemes foster university-industry collaboration – some are focused on pure research – but my focus here is on the schemes that do foster such collaboration. Currently, among these, the ARC manages the Linkage Project scheme, the Industrial Transformation Research Program, the ARC Centres of Excellence scheme, and the Special Research Initiatives which supported the bionic eye project. All these schemes seek to encourage collaboration between multiple partners. The NHMRC administers numerous funding schemes, including collaboration-oriented Project Grants, Program Grants, Development Grants, Partnership Projects, and Centres of Research Excellence.

The 2015 Watt Review drew attention to the weaknesses in the grant application system. Specific recommendations were made to and accepted by the government. Among these: the ARC Linkage Projects scheme should move from calling for applications once year a year to a continuous process, and the scheme's outcomes should be announced within a maximum of six months from the date of submission (Watt, 2015, p. 45).

The changes are welcome. More controversial is the recommendation that universities take an increasingly active role in scrutinizing and filtering out potential applications which are less competitive (Watt, 2015, p. 46). As Jensen and Webster note, this shifts time and costs from the agencies to the universities. Still, methods could be developed, with government assistance, to enable universities to work more effectively with their researchers when applying for research funds (Jensen & Webster, 2016, p. 189).

As Watt highlights, both agencies share fundamental weaknesses in their application processes. O'Kane identified similar issues in her review of the CRC Program. Among them: an overly complex and time-consuming grant application process, and equally burdensome project accountability (O'Kane, 2008, pp. xiv, xiii). Addressing these

195 Trounson returned to Australia in 2013 where he is co-founder of the biotechnology firm Cartherics Pty Ltd and Distinguished Scientist of the Hudson Institute. In 1991 he co-founded the institute, then named the Monash Institute of Reproduction & Development.

weaknesses would clearly boost the efficiency and appropriateness of the application processes. And not just for researchers. Funding bodies face a "substantial burden" and workload associated to the administrative, peer review and panel assessment processes, according to Ian Watt (2015, p. 44).

A key weakness is that funding proposals are extensive documents. Herbert and colleagues (2013) found that applications are between 80 and 120 pages long. (A review panel of 10-12 senior researchers are then expected to read and rank 50-100 such proposals). Based on their NHMRC case study, Herbert's group found that the key scientific information needed to assess an application is just nine pages.

Following Herbert et al. (2013) and Simon McKeon et al.'s 2013 *Strategic Review of Health and Medical Research*, I recommend that both the ARC and NHMRC simplify their application process. A place to begin is a staged or layered review in which initial proposals are tightly focussed on the scientific heart of the project, the equivalent of Herbert and colleagues' nine pages.

Although a 2006 NHMRC trail designed to improve the application process was unsuccessful -- it unexpectedly increased the number of proposals by 30% – there are successful international programs which could provide valuable ideas. The US and UK, for example, have adopted a staged application process which begins with an expression of interest, requiring scientific not administration information. Short-listed applicants are then invited to submit a full application (Herbert et al., 2016, p. 5; Watt, 2015, pp. 44–45).

This approach has proven effective. For instance, a review of the multi-staged UK Engineering and Physical Sciences Research Council (EPSRC) Platform Grant[196] scheme found the number of proposals submitted nearly halved over time. Further, the success rate increased after EPSRC introduced strict eligibility rules such as a limit on the number of times unsuccessful applicants can resubmit a reworked proposal (Herbert et al., 2013, p. 5).

According to Tony Willis, Executive Director, Research Programs Branch, the NHMRC in 2013 reduced the number of "fields", or issues, to be addressed in an application by "nearly 50 percent" (Willis, interview, 2017). The NHMRC completed a Structural

[196] See https://www.epsrc.ac.uk/.

Review of its grant programs in mid-May 2017.[197] Launched in July 2016, the review followed-on from public commentary, including by Herbert et al. (2013), concerning pressures on grant applicants and expert peer reviewers from granting arrangements. Of particular concern was the amount of grant-writing time spent by researchers.

It makes sense for the ARC to follow the NHMRC's lead when dealing with science-oriented applications, the subject of this thesis, and to consider the relevance of findings such as those by Herbert and colleagues. Initial applications could be simplified, covering the scientific case for the proposal. Successful applicants would be invited to submit a full-application. Where necessary, ARC experts could work with applicants to improve their applications.

Criteria required for stage-two full applications could be devised to ensure potential collaborators work together from the beginning on overall project planning and on establishment of consensus on the goals, procedures, and management and governance structures of the project. Additional matters to include are agreement upon the approach to patents and other commercial aspects of research translation. Disputes over these sorts of issues are mentioned frequently by participants as barriers to innovation.

As well as investigating a simplified, multi-staged application process, ARC and NHMRC review committees could evaluate administrative approaches used by the funding bodies themselves. Ideas to consider include increased use by the funding bodies of expert panels to assess market-oriented research proposals, the evaluation criteria used by expert and peer review panels and disciplinary-based standing committees.

Overall, a simplified funding procedure could have positive spill overs to both funding bodies, beyond the administration of the grant application process. It could enable them, for instance, to streamline their own structures and procedures, opening-up an opportunity to provide additional support as necessary, especially to short-listed or outstanding applicants.

This recommendation relates more directly to recurring funding schemes such as the ARC Linkage Projects scheme than to special initiatives such as the bionic eye. Special

[197] See https://www.nhmrc.gov.au/grants-funding/structural-review-nhmrc-s-grant-program. Changes were announced 24 May, 2017, after I completed research for this thesis. See http://stagingconnections.org/eventstream/ACT/NHRMC.html.

initiatives are likely to have their own specific application requirements, but these are still likely to be influenced by general expectations about the length and detail required in applications. In fact, the behind the scenes jockeying, the media articles, the quiet review and the eventual bionic eye special initiative led to a much less efficient process than a staged process beginning with expressions of interest could have been.

In sum, the objective of reviewing and simplifying the funding processes used by the ARC and NHMRC is to reduce unproductive time by all participants in the process. Doing so would boost productive collaboration, and, ultimately, enhance the transition of ideas from the laboratory to the marketplace.

Recommendation 8 (Collaboration): Broaden the indicators, or metrics, used by universities to assess researcher performance to include collaboration measures of engagement and impact

Rationale

Changes in the criteria used to evaluate the performance of academic researchers by their universities may potentially encourage collaboration within fields, as well as with other research institutions and industry. With enhanced collaboration may come fresh and productive ideas in both fundamental and applied research.

Objectives

1. Reduce the tendency of researchers to work in professional silos in which they seek to maintain dominance of a research area by excluding perceived competitors.
2. Reduce the emphasis on the quantity of publications from a research project and increase the emphasis on quality.
3. Encourage researchers to pursue risky but potentially commercialisable topics which may not produce results quickly enough to maintain a steady flow of publications.
4. Encourage researchers, especially EMC scientists, to move between academia and industry by reducing fears that the "damage" to their publication record due to time spent in/working with industry will have a negative impact on their career path.

Target group

Although the Excellence in Research for Australia (ERA)[198] program evaluates performance of the university sector, individual universities will be responsible for implementing revised metrics used by universities to evaluate the performance of their research staff. However, as the metrics used by individual universities will reflect those used in ERA, there will be a strong role for federal support and for input from industry and stakeholder groups such as Universities Australia.

Discussion

In Chapter 6, Academic Culture, I noted that all employers need clear methods for evaluating the work of their employees. Currently, while a researcher's success in obtaining funding is important, the number and impact of publications remains a dominant criterion, or metric, shaping decisions about a researcher's promotion, salary and overall career progression. Publication metrics are attractive because they are easily identifiable and quantifiable (Shepherd, 2015, p. 18).

Additionally, as I also discussed in Chapter 6, publication success is important at the institutional level. It is one of the criteria used to evaluate the reputation and global ranking of universities which, in turn, is important to a university's ability to attract staff, students and funding. Institutions seeking to maintain or boost their reputation and global ranking may push researchers to avoid projects with uncertain, but potentially important outcomes to keep up the flow of publications.

Jensen and Webster (2016) are correct to point to Goodhart's Law, paraphrased as "when a measure becomes a target, it ceases to be a good measure". The pressure to publish early and often is no guarantee of quality research outcomes or of a researcher's overall performance. It is largely a measure of their ability to meet the measure itself (Jensen & Webster, 2016, p. 190). As Participant 28 observed, it puts "wheel-cranking" ahead of good science.

Instead, what is needed is a more comprehensive reward system for scientists, one that reduces pressures to publish, expands measures of so-called outputs such as stakeholder engagement and patent activity, balances researchers' commitment to both fundamental

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198 See http://www.arc.gov.au/excellence-research-australia.

and applied science, and recognises that not all research projects will have immediate outcomes, quickly convertible into profile-enhancing publications. Projects leading to delayed or slow publication are not necessarily a sign that the work is ill-conceived. In fact, such projects may be breaking new directions, and could in time prove to be intellectually and/or commercially highly valuable.

The nature of university metrics is directly relevant to university-industry collaboration. As discussed in Chapter 7, academic metrics are at odds with industry metrics. It is publications versus patents, products and profits. This culture clash is a barrier to productive collaboration between the sectors.

Steps to extend researcher metrics are being taken by individual institutions. To illustrate, the University of New South Wales Faculty of Engineering considers successful collaboration with industry in staff promotions, and the University of Technology Sydney has extended industry impact measures across the institution (Hoffman, interview, 2016; Green, personal communication, 8 March 2017).

I have not discovered any formal moves to re-evaluate academic metrics used by the university sector to evaluate the performance of researchers. But Green acknowledges they are being "comprehensively" discussed within the wider university community. One driver of the discussion is the ERA program which I discuss in more detail below.

At the funding body level, the NHMRC works, informally, with peer reviewers to promote the use of more "sophisticated output measures" by universities, says Tony Willis. In its own work, the Council recognises the principles of the 2012 San Francisco Declaration on Research Assessment (DORA)[199] which recommends ways to improve the evaluation of research output. Further, the Council recently provided guidance to peer reviewers on recognising industry-relevant experience in funding applications[200] (Willis, interview, 2017).

Changes are also afoot at the ARC. While not involved directly in reshaping measures used by universities in staff performance reviews, the Council is engaged in two projects looking at the strengths and weaknesses of the nation's universities. Both

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[199] See http://www.ascb.org/dora/.

[200] See https://www.nhmrc.gov.au/book/guide-peer-review-2017/4-principles-obligations-and-conduct-during-peer-review.

projects are already encouraging a rethink of academic assessment measures used by university administrators.

The first involves the ERA program. The program's goals are to identify national strengths and weaknesses, create incentives to improve the quality of research, and identify emerging research areas and opportunities for further development. Results are obtained by collecting data from universities and comparing it to international benchmarks. The Council is developing assessment criteria for the 2018 evaluation, and anticipates implementing broader measures in its assessment of individual university performance.[201]

Meanwhile, under the auspices of the National Innovation and Science Agenda, the ARC is engaged in the development of a new set of measures aimed at evaluating the performance of Australia's universities in regards to their non-academic impact and their industry and "end-user" engagement. The Council is running a pilot of this Engagement and Impact Assessment process ahead of a full assessment in 2018. It will run alongside ERA 2018 as a companion exercise.[202]

To that end, a steering committee has been established and a technical working group is consulting with universities to provide advice regarding the development of appropriate methodology and measures of research engagement and impact, suitable for different disciplines and end-users. A Performance and Incentives Working Group will advise the ARC about how the preferred model will influence the decisions made by universities regarding the focus of their research activities.[203]

Clearly, the time is right for a concerted effort to revise the indicators used by universities in the assessment of research staff performance. One way to proceed would be for concerned researchers and administrators to push Universities Australia to hold a round table discussion on the topic. Goals could be formulated and strategies discussed, setting the stage for action at the university level.

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201 See http://www.arc.gov.au/excellence-research-australia.

202 See http://www.arc.gov.au/ei-pilot-overview.

203 See http://www.arc.gov.au/ei-steering-committee-and-working-groups.

Recommendation 9 (Collaboration): Establish a National Industry Placement Scheme for doctoral students and post-doctoral researchers

Rationale

A national industry placement scheme would provide an opportunity for early-career researchers (ECRs) to acquire skills needed to build a career outside academia. During their placements, ECRs could provide a bridge between industry and academia, one which increases opportunities and connections between the two cultures.

Objectives

1. Provide ECRs with access to equipment and expertise not available in universities. This could include expertise in management and communication, as well as in business development and science translation.
2. Demonstrate to ECRs the value of advanced research and management skills to industry, along with the prospect of a career as an intermediary working with both academia and industry.
3. Demonstrate to industry the value highly trained scientists can bring to their business.
4. Provide an opportunity for established academic and industry experts to learn to communicate effectively with one another, value collaboration, and build long-term connections.

Target group

Leadership should come from the Commonwealth Government. Innovation and Science Australia (ISA) is ideally suited to develop an appropriate operational and funding structure for a National Industry Placement Scheme. ISA could collaborate with the Australian Mathematical Sciences Institute (AMSI) and Universities Australia.

Discussion

There are no easy answers to the problem of poor collaboration between the university and private sectors. The only certainty is that, as discussed above and in chapter 2, it contributes to Australia's "lacklustre" performance on international rankings of academic-industry collaboration (Marsh, Western, & McGagh, 2016).

As a step forward, recommendations 7 and 8 provide ideas for reducing the reluctance academic researchers may feel about collaborating with partners outside the university sphere. Recommendation 9 is a suggestion for improving the skills needed for serious and sustained university-industry collaboration. Although the recommendation focusses on emerging scientists, it indirectly brings together senior academic researchers and industry experts, which may enhance their mutual understanding and ability to collaborate.

With the current government focus on 'innovation' and 'entrepreneurship', universities have been prompted to boost their participation in private sector endeavours. As well, some are developing or participating in programs to give undergraduate and postdoctoral students the opportunity to develop business skills. There is a growing number of multi-university programs designed to provide students with first-hand industry experience. Examples include the Australian Technology Network of Universities,[204] the Industry and PhD Research Engagement Program[205] in Western Australia, and the AMSI intern program.[206]

I suggest a federally-funded national industry placement scheme would add significantly to such efforts, as recommended by ACOLA's recent review of Australian's research training system.[207] To borrow from John McGagh, chair of the ACOLA working group, and his deputy chairs Helen Marsh and Mark Western, such a scheme could be the "heart" of the way forward for effective multi-sector collaboration (Marsh et al., 2016).

A national industry placement scheme could build on the traditional role of the postdoctoral position as a "training period", one which Hardy and colleagues say bridges the divide between new graduates and a permanent academic career. It could include doctoral students, as well as postdocs, enabling universities to better equip their students and postdocs for an ever-changing job market (Hardy et al., 2016, p. 1).

The latter is especially important. AAS officers Les Field and Andrew Holmes (2016) note that doctoral students need to be prepared for, "and less shocked by", the reality

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[204] See https://www.atn.edu.au/about-us/.

[205] See http://www.iprep.edu.au/.

[206] See http://amsiintern.org.au/.

[207] See http://www.researchtrainingreview.org.au/.

that many will end up working, not in academia, but in government or industry. Only 2 per cent of recent PhD graduates are expected to enjoy an uninterrupted academic career leading to the professorial level (Field & Holmes, 2016).

The ACOLA review points to a successful Canadian program as a model. Formerly called the Mathematics of Information Technology and Complex Systems, Mitacs is a not-for-profit organisation that manages and funds research and training programs for ECRs. Partners include universities, industry and the federal government. Open to all disciplines since 2007, Mitacs has supported over 10,000 research internships, trained more than 19,000 ECRs, and backed nearly 1,400 international research collaborations.[208]

In his 2015 report on research and funding arrangements, Ian Watt called for $12.5 million to deliver a new "business placement initiative". I agree with the ACOLA recommendation that the funds be used to establish a Mitac-style industry placement scheme. But instead of starting from scratch, I suggest building on the AMSI Intern Program. Less ambitious than Mitac, it is, nonetheless, modelled on that scheme. Further, if the internships were prestigious and competitive they could become a valuable line on a curriculum vitae, along with publication (ACOLA, 2016, p. 60; Geddes, personal communication, 22 October 2016; Watt, 2015, p. iii).

The AMSI intern Program was established by the Victorian State government in 2007, and like the early days of Canada's Mitac program, it focussed on the mathematical sciences. The scheme was expanded in 2010 through a 3-year partnership with Enterprise Connect, a Commonwealth initiative. In 2015 the AMSI program negotiated 3-year partnerships with eight AMSI membership universities in Victoria and New South Wales, and supported internships in all disciplines. Today, it funds 3-5 month, tightly focussed postdoctoral placements with small to large businesses (Geddes, personal communication, 22 October 2016; http://amsiintern.org.au/).

According to Geddes, the AMSI Intern Program has a "96% satisfaction rating with industry partners".[209] With dedicated federal funding, I argue it offers a trusted and established platform on which to build a national program, one which could be

[208] See http://www.mitacs.ca/en/.

[209] An informative follow-on project would be to compare industry's perception of the value of the program with that of participating universities.

gradually expanded to include doctoral students. The outcome could be a 'win-win-win' for students, university researchers and industry experts unused to working with academe.

Recommendation 10 (Collaboration): Establish a range of measures to support the development and operation of university-industry precincts

Rationale

A diversity of measures for supporting university-industry precincts would increase the development and on-going viability of local, city-based, and regional precincts, along with the university-industry collaboration such precincts promote. The benefits are numerous, building on the productive relationships nurtured by functional precincts.

Objectives

1. Enhance the ability of people within the sectors to interact, formally and informally.
2. Establish long-lasting connections. Working relations made in precincts often persist after participants move apart geographically and enhances the positive impact of internet and other communication technologies.
3. Increase visibility and status of participants. The higher profile attracts early-stage investors, businesses and academic and industry talent from outside the precinct.
4. Stimulate the local economy.

Target groups

While individual universities are taking early steps towards building precincts or enhancing existing ones, these efforts are primarily funded by attracting some form of federal funding. To escalate the process, the Commonwealth should initiate the effort to develop a coordinated range of measures to support the development and operation of university-industry precincts.

Discussion

Universities and industry partners in Australia and around the world are putting proximity -- the geography of discovery -- to work in the process of innovation. They are developing and participating in what I call ‘precincts’, geographical concentrations of interconnected universities and science and technology businesses.[210]

While many consider that the precinct began life in California’s Silicon Valley, the concept has a long history. In his 1890 publication, *Principles of Economics,* British economist Alfred Marshall considers “The Concentration of Specialized Industries in Particular Localities”, noting that from “an early stage in the world’s history” co-location brought financial benefits to the villages and regions in which they developed (pp. 328–332).

Still, Silicon Valley, is considered “the mother” of all precincts and the exemplar of university-industry collaboration. Kick-started by Russia’s 1957 launch of Sputnik 1 and the resulting cold war competition, it reflects key characteristics shared by many of today’s most successful precincts. Among these are a research-intensive university sector, a strong venture capital industry, a culture of experimentation that tolerates risk and failure, and a role for government, including procurement schemes discussed earlier in this chapter (Funnell, 2016, p. 7 of transcript; Office of the Chief Scientist, 2015, p. iv; Sohn, 2016, p. 40).

University of Manchester innovation authorities Elvira Uyarra and Ronnie Ramlogan say the consensus of scholarly analysis is that such geographical concentrations bring benefits, among them a boost to the professional profile of participants in a precinct (Uyarra & Ramlogan, 2016, p. 216). As well, work by economist Ajay Agrawal and marketing expert Avi Goldfarb suggests that once people have established an in-person relationship, they continue to collaborate effectively via online networks. “When those relationships are established, they can go anywhere in the world,” says Agrawal (quoted in Sohn, 2016, p. 41).

The presence of active precincts also boosts the economic wellbeing of associated cities and regions, as observed by Alfred Marshall. Moreover, a precinct makes the cities and regions where they exist more resilient in the face of financial downturns, according to Scott Stern, an economist (Sohn, 2016, p. 41). Nonetheless, there can be economic downsides, find Uyarra and Ramlogan. For example, in their study of 17 global

[210] Other common terms for science and technology precincts in the literature include ‘clusters’, ‘innovation ecosystems’, ‘hubs’, and ‘geographic clustering’. While I borrow from Porter’s definition of ‘cluster’, I prefer ‘precinct’ because it denotes a physical location, along with a sense of focussed research or activity.

precincts[211] they found that precincts which overspecialise may be unable to adapt to "external shocks". Precincts can also pull benefits from other precincts, can trigger congestion which inhibits collaboration, and drive up the cost of land and salaries (Uyarra & Ramlogan, 2016, p. 199).

According to Uyarra and Ramlogan, most precincts evolve spontaneously and are then followed by a deliberate policy effort. At a more specific level, they identify a number of features that are regularly associated with a precinct's performance. Among these are the personal capabilities of the managers and the presence or absence of a dedicated leadership team. The quality of support services is also important. These services include programs for mentoring, technical support, business planning, and networking.[212] Precincts also tend to use public sector funding to attract, or leverage, private sector investment (Uyarra & Ramlogan, 2016, pp. 213–215).

But along with these broad similarities, there are equally broad differences. As Harvard economist Michael E. Porter says, precincts "vary in size, shape and state of development" (Cited in Uyarra & Ramlogan, 2016, p. 197). That observation applies to Australian precincts. There is, nonetheless, one thing all Australian precincts have in common: they are an attempt to overcome the "tyranny of distance"[213] between collaborators, actual or potential, living in different parts of the country or in poorly connected cities (Gilding, 2008, p. 1132). As reported in Chapter 9, the tyranny of distance was cited by participants as a major barrier to collaboration within the BVA.

Among Australia's earliest precincts are those that built upon existing universities and research institutes in Victoria and Queensland. There, the state governments adopted strategies to build the intellectual and industrial capacity of their jurisdiction. The Victorian government launched its *Biotechnology Strategic Development for Victoria* in 2001, and in 1998 Queensland announced it was planning to become a *Smart State* (Gilding, 2008, p. 1134; Wheeler, 2012).

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211 Their methodology included a review of relevant policy evaluations and related academic literature. The precincts, what they call clusters, were located in Europe, the UK, Scandinavia, Brazil, Japan and Canada.

212 There are many names for precinct programs. Among the most common are 'internships', 'hub's, 'accelerators', 'incubators', and 'landing pads'. Academic institutions may also establish these and other programs in the absence of a formal precinct.

213 The concept was first brought to widespread attention by historian Geoffrey Blainey in his 1966 book *the Tyranny of Distance: How distance shaped Australia's history*.

Today, both states are home to internationally recognised biotechnology precincts. And Victoria's Geelong Technology Precinct concentrates on advanced manufacturing, materials and engineering (Gilding, 2008, p. 1134). Elsewhere across the country, individual universities have made "significant investments" in precincts, says Green[214] (Green, 2015, pp. 50–51).

Given that each of these efforts varies in size, shape and state of development, it makes no sense to adopt a one-size-fits all approach to supporting their ongoing activities. A range of support mechanisms and funding options would allow precincts to build on their existing strengths. That is also true for future efforts to develop university-industry precincts. However, for new precincts the optimal policy would "push the system gently toward favoured structures that can grow and emerge naturally", while endeavouring to minimise potential drawbacks (Uyarra & Ramlogan, 2016, pp. 199, 227).

In sum, I argue that a flexible suite of measures designed to boost Australian precincts would enable existing and developing precincts to support themselves, based on their individual requirements and strengths. More precincts, more collaboration. Further, built into the suite should be instruments directed towards overcoming barriers to collaboration with international precincts, especially those in the booming, neighbouring markets of Asia. With carefully designed policies, what Gilding (2007) calls today's "partial" ties to those markets could be boosted to regular ties, benefiting all participants (p. 1132).

Translation Environment: "[We need] to have a greater awareness of the difficulties of translation of research into benefits for the community" (Participant 17)

Throughout this chapter I have referred to 'translation'. Although the word is often used synonymously with 'innovation', I follow economist T. Randolph Beard and his colleagues and use it here to discuss the final stage in the complex, iterative, intensely human process of innovation. It is the stage during which product or process prototypes are refined then "diffused and integrated" into the wider society. This is how a nation

[214] Among them, the University of Melbourne in Victoria; in New South Wales, the University of Technology Sydney, the universities of Wollongong, Newcastle and, more recently, Macquarie; in Queensland, the University of Technology and Queensland University; and in South Australia, the universities of Flinders and South Australia.

maximises the benefits of its research capacity[215] (Beard, Ford, Koutsky, & Spiwak, 2009, p. 354).

Barriers to translation, like barriers to the overall process of innovation, are numerous and complex. Most approaches to reducing this complexity are aimed at the business sector. For example, NISA currently lists 29 initiatives designed to support innovation. Nearly half of these target translation difficulties experienced by the commercial sector, whether tiny firms or large corporations. In contrast, my recommendations seek to boost translation by looking at the academic sector.

Further, as with many of my recommendations, those in this section could be discussed under more than one of the headings already covered in this chapter: Continuity, Funding, and Collaboration. But because the underlying issues they address were frequently raised together by participants, I have given them their own category: Translation Environment.

I begin with a recommendation geared to enhancing the abilities of universities to manage the industry-linked complications of translation.

Recommendation 11 (Translation environment): Promote the employment of 'intermediaries' within university offices or programs dealing with academic–industry relations

Rationale

Increased employment by universities of intermediaries -- people with expertise in both the academic and industry sectors -- would facilitate relationships with industry which, in turn, might boost the transfer of university-generated ideas and prototypes to the wider society.

[215] Although 'translation' is widely employed in the health and medical context, I take a broader view. Again, in my analysis, it is the final hurdle of all scientific research which sparks a commercially-oriented idea.

Objectives

1. Facilitate university-industry relations by utilising the expertise of intermediaries to streamline the on-going and often-inefficient, costly and time-consuming procedures surrounding engagement with industry.
2. Assist university researchers keen to translate their findings themselves or with industry partners.
3. Enhance interaction between universities and spin-off companies established by staff researchers and their industry partners.
4. Increase the amount of non-grant income earned by universities by increasing external understanding and use of university facilities and expertise.

Target group

Recognition of the value of working with intermediaries on university-industry interactions may begin at many levels of a university, for example within a science faculty or a corporate relations office. However, the decision to employ specific individuals to assist with academic-industry relations rests with senior university management, at the Deputy Vice-Chancellor (VC) or VC level. These senior administrators have the authority to identify clearly where and how to best utilise their expertise.

Discussion

While many Australian universities are widening their in-house business relations expertise, the focal point is often improved intellectual property activities. The University of Queensland's UniQuest, for instance, was established in 1984 to commercialise technology developed by the university and its partner institutions. That remains its primary activity.[216] Such action is welcome, and is considered later in this chapter, but these efforts on their own are "not as important as bridging more fundamental gaps between the goals and capabilities of the parties" (AIG, 2016, p. 17).

[216] See https://www.uq.edu.au/news/article/2012/05/uniquest-promotes-uq-innovation-world-water-conventions and https://uniquest.com.au/about-uniquest.

In other words, not as important as bridging the gulf between the over-arching cultures of academe and industry.[217]

This is a task for what Participant 26 calls “trusted intermediaries”, people with a “leg in both camps”. In the US, for example, individuals with both industry and academic experience play a central role in the innovation process. It is a respected career path, separate from hands-on research or business management. But in Australia, “there’re very, very, very few people who do that work” (participant 26). Participants with US experience claim intermediaries can play a very useful part in the transfer of knowledge from the laboratory to the market. Not only are intermediaries ‘bilingual’, able to speak the language of both industry and academe, their first-hand knowledge of the values and goals of industry can help universities to establish more accessible, efficient and cost-effective procedures for boosting collaboration with the commercial sector.

There is not yet, though, a body of evidence supporting the burgeoning perception in academic circles that such intermediaries should be found, developed, and employed by universities. Still, scholars recognise the “substantial barriers” to successful university-industry collaboration (Bruneel et al., 2010, p. 866), and they have begun exploring the design and development of university-based technology transfer organisations (Debackere et al., 2005). Although I was not able to identify studies focussing on the role and performance of university-based intermediaries[218], the literature clearly identifies the value of increasing the number of university staff with the kinds of expertise they hold (Chapple, Lockett, Siegel, & Wright, 2005; Siegel, Waldman, & Link, 2003).

In Australia, the trend of hiring intermediaries for more than commercialisation activities is building. Some institutions are hiring or planning to hire experts. Some already have relevant appointments and structures in place. The University of New South Wales (UNSW), to illustrate, established an Enterprise Division and created the position of Deputy Vice-Chancellor to oversee a growing team of intermediaries, working at both the division and faculty levels (UNSW media release, 11 July 2016).

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[217] See Chapter 7, *Culture Clash: The Influence of Industry and Political Cultures,* for an analysis of the issue from the perspective of case study participants.

[218] This role is distinct from another area well covered in the literature, ‘academic consulting’, which focusses on the role of individual researchers seeking to promote their findings to potential industry partners, or to provide fee-paying technical services to the private sector. See, for instance, Perkmann & Walsh, 2008.

The Faculty of Science, alone, has six full-time equivalent Relationship Managers, all of whom have hands-on industry experience (Hoffman, interview, 30 August 2016).

The University of Technology Sydney (UTS) is also employing intermediaries. In 2015, it hired Australia's first Industry Professor to promote greater engagement with Industry, along with advising staff on university-industry teamwork. The role also involves driving collaborative initiatives. Examples include the UTS-industry hub, the Knowledge Economy Institute, and the Food Agility Cooperative Research Centre. To help support broader industry engagement, the Research and Innovation Office has nine dedicated intermediaries based in the Faculties of Engineering and IT, Science, Business, Health and Design, as well as offering sector expertise (UTS media release; Kukulj, interview, 5 May 2017).

These are just two examples. Nonetheless, they represent the acknowledgement by the academic community that if it wants to maximise the discoveries and advances made by its researchers, it makes sense to learn how to work more effectively with industry. One way to do so is to hire intermediaries. The move fits with the rise of university-industry precincts, along with the move to provide doctoral students with industry experience. Interviewees, especially those with industry and academic experience, said ongoing participation by intermediaries in the bionic eye initiative might well have prevented much of the organisational, administrative and internal dysfunction experienced by BVA.

Recommendation 12: (Translation environment) Adopt a single and simplified approach to intellectual property across the university and publicly-funded research sectors

Rationale

Adoption of a simplified and unified intellectual property (IP)[219] model by universities and publicly-funded organisations[220] would reduce the complexity, cost, and time now

[219] I follow the definition of intellectual property rights (IPR) set out by the World Intellectual Property Organization, or WIPO. IPR allow creators or owners of patents, trademarks or copyrighted works to benefit from their own work or investment in a creation. Patents are of direct relevance to this thesis. They provide owners with protection over the invention, along with the right to enable others to use it via licenses and other contractual agreements. See http://www.wipo.int/edocs/pubdocs/en/intproperty/450/wipo_pub_450.pdf.

[220] Henceforth abbreviated as universities.

involved in taking knowledge from the research sector to users and the market place, thereby boosting the successful translation of research.

Objectives

1. Simplify the management, establishment and ownership of intellectual property (IP) by universities.
2. Reduce the likelihood of tensions over potential IP.

Target

Senior university administrators, in consultation with researchers and dedicated knowledge translation staff, must make the final decision regarding the intellectual property model used by their institutions. They could, however, coordinate efforts to assess various IP models through peak bodies such as Universities Australia, the Academy of Science and Science and Technology Australia.

Discussion

There are few topics upon which both my academic and industry participants agree. One of them is intellectual property – both sectors condemned the current state of affairs.[221] There is plenty of evidence that their negative perception is the rule, not the exception. Further, various university-driven IP barriers have been identified by experts (AIG, 2015).

There are long-term, as well as immediate, consequences to the stumbling blocks posed by badly managed IP. As Kevin Cullen, CEO of UNSW Innovations and his UNSW colleague Brian Boyle explain, this happens when knowledge is "compartmentalized and restricted", making it too hard or too expensive for even discovery teams to pursue promising results (Boyle & Cullen, 21 September 2016). Similarly, as the Productivity Commission noted in its recent report *Intellectual Property*, patent protection may "perversely inhibit" other teams from advancing the patented knowledge (Productivity Commission, 2016, p. 13).

In Australia, the AIG finds universities too often approach IP in "seriously inconsistent ways" involving "a confusing mass of idiosyncratic contracts and internal procedures

[221] For participant comments see the discussion of intellectual property in Chapter 9, *Geography, People & the Valley of Death.*

that can be expensive and time consuming for business to navigate". It also argues that universities often encourage researchers to claim so much of the real or potential IP that firms see no value in partnering with the sector. As AIG's report states, trouble with IP can "nip collaboration in the bud" (AIG, 2015, p. 38).

The AIG's findings are consistent with those of Ian Watt in his review of the nation's research policy and funding arrangements. To the AIG's list Watt (2015, p. 57) adds over-valuation by some universities of the financial potential of their IP. The immediate consequence of such difficulties is that universities may spend more on technology transfer lawyers, officers and advisors than they get back from the technology transfer itself (Hoffman, interview, 30 August 2016).

University revenue from IP is, in fact, only a small percentage of the sector's non-grant income. To illustrate, analysis of data collected by the Higher Education Funding Council for England, reveals IP revenues there constituted a mere 2% of non-grant income (Ulrichsen, 2014, p. 22). The situation is marginally better in Australia. Cullen used recent data from the National Survey of Research Commercialisation to find that IP generated an average of 4.5% of all non-grant revenue obtained by Australian Universities in 2014 (Cullen, e-mail, 27 September 2016).[222]

Efforts are underway to improve the framework for managing IP generated by Australian universities. Since 2001, for instance, the ARC and the NHMRC have required that institutions administering grants must have IP management and data sharing policies in place in order to receive funds (Watt, 2015, p. 58).

This policy was complimented in 2007 by the Australian Code for the Responsible Conduct of Research[223] and the National Principles of Intellectual Property Management[224] for publicly-funded research. The Code outlines good practice protocols for publicly-funded research, and the Principles provide guidance for the ownership, promotion, dissemination, exploitation, and protection of such research. But as Watt

[222] See https://www.industry.gov.au/innovation/NSRC/Data/Pages/default.aspx.

[223] See https://www.nhmrc.gov.au/guidelines-publications/r39.

[224] See http://www.arc.gov.au/national-principles-intellectual-property-management-publicly-funded-research-0.

notes, “neither the Code nor the Principles include mechanisms for reporting or monitoring compliance with these provisions” (Watt, 2015, p. 58).

At a more practical level, IP Australia, the nation’s IP agency, has implemented two schemes designed to facilitate the transfer of knowledge created by the publicly-funded research sector. The Australian IP Toolkit for Collaboration[225] contains a model contract and confidentially agreements, along with guidelines on developing partnerships and managing IP. Source IP[226] is a digital marketplace for sharing information, similar to other globally available databases.

Additionally, IP Australia has established a fee-for-service group of in-house experts. By contacting the Patent Analytics Hub,[227] publicly-funded research organisations can obtain an analysis of patenting in their area of interest, along with other information such as trends, target markets, and networks between organisations. While IP Australia’s tools are a welcome development, they are not sufficient to overcome the existing barriers[228] (Jensen & Webster, 2016, p. 190).

While there is clearly no panacea, there is, nonetheless, an approach that has proven successful internationally. The Easy Access IP model was developed at the University of Glasgow by Kevin Cullen and is gradually being implemented by Australian Universities.[229] Using simplified one-page contracts, Easy Access IP gives specific research discoveries, inventions and intellectual property to companies and individuals for free (Cullen, e-mail, 8 April 2017).

In return for free access to the knowledge – often, though not exclusively, at an early stage of development and requiring significant financial investment and R&D – the licensee must agree to:

- Demonstrate how they will create value for society and the economy.

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225 See https://www.ipaustralia.gov.au/understanding-ip/commercialise-your-ip/ip-toolkit-collaboration.

226 See https://www.ipaustralia.gov.au/understanding-ip/commercialise-your-ip/source-ip

227 https://www.ipaustralia.gov.au/tools-resources/patent-analytics-hub

228 Jensen and Webster claim that a “less mechanistic” approach to IP would “yield benefits to the community at large”. I agree.

229 See http://easyaccessip.com/.

- Acknowledge the licensing institution as the originator of the intellectual property.
- Report annually on the progress on the development of the Easy Access IP.
- Agree that if the IP is not exploited within three years, the licence will be revoked.

- Agree that there will be no limitations on the licensee's use of the IP for the university's own research (http://easyaccessip.com/).

The UK National Centre for Universities and Business (NCUB) concluded in 2015 that while it is still early days, Easy Access IP has, among other benefits, resulted in more efficient use of staff time and legal costs. However, it has not helped with the preliminary process of finding industry partners. Of particular relevance to Australia, says Watt, is that the "vast majority" of arrangements here are with small to medium enterprises, or SMEs (Watt, 2015, pp. 59–60). Here, SMEs tend to be more innovative than large companies, and are less able to fund the expense of acquiring conventional patents (Eggington, Georghiou, & Burdach, 2015, p. 5;

Early assessments are generally positive, but not unanimous. The Productivity Commission (2016, p. 484) concluded it was too soon to assess the model, along with others such as Source IP. But the NCUB found that "Easy Access IP has widened the debate about KE [knowledge exchange] mechanisms, and added another approach and more flexibility to the KE toolkit which is helpful" (Eggington et al., 2015, p. 5). Watt agrees. He encouraged the Commonwealth to obtain advice on "the merits" of extending the use of the Easy Access IP model across the publicly-funded research sector, and, if relevant, propose implementation arrangements nationwide (Watt, 2015, p. 64). I strongly support Watt's recommendation.

Recommendation 13 (Translation environment): Develop a flexible regulatory system for late stage biotechnology developments

Rationale

Inflexible regulatory regimes can hinder translation. Introduction of a flexible regulatory regime which permits universities and/or businesses to test or trial prototypes more efficiently and cheaply, while providing community safeguards, would help to boost the commercialisation of new products and processes.

Objectives

1. Promote the ability and willingness of small groups to take new products and processes to market in Australia, rather than selling their intellectual property rights (IPR) to overseas interests.
2. Encourage researchers and their industry partners to take on promising projects that may require more flexible, fit-for-purpose testing regimes than now exist.
3. Commercialise new products and processes faster and more cheaply, benefitting consumers as well as the group commercialising the knowledge.
4. Guarantee product safety and quality to increase acceptance by customers.

Target groups

The Commonwealth government has responsibility for setting most regulations and establishing the key regulatory authorities which impact scientific translation. While regulatory roles fall to different agencies, the Health, Safety and Environment (HSE) Working Group coordinates government regulators and related policy, research and funding agencies.[230] It is well placed to oversee implementation of this recommendation.

Discussion

Australians often joke that they live in a country that is over-regulated where it does not matter and under-regulated where it does. This is an opinion commonly held by case study participants, especially those with industry experience. They are critical of the regulatory hurdles they must leap in order to test and commercialise their ideas. No doubt, many would be surprised that when it comes to the quality[231] of the country's regulations, Australia ranks fifth out of 128 countries on the 2016 Global Innovation Index[232] (Dutta, Lanvin, & Wunsch-Vincent, 2016, pp. 311, 394).

230
https://industry.gov.au/industry/IndustrySectors/nanotechnology/SafetyStandardsAndRegulations/Pages/Regulation.aspx.

231 According to the GII, "regulatory quality" is the "Index that captures perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private-sector development".

232 Singapore takes first place in regulatory quality, followed in order by Hong Kong, New Zealand and Finland.

Regardless, participants are correct to link national and state regulations to their ability to efficiently take new products or processes to market.[233] This is an issue that global innovation academics are investigating as they seek to identify how regulations hinder or promote research translation. The goal is to establish regulation as a possible instrument for innovation policy (Blind, 2016, p. 450).

There are three types of regulations that impact innovation. "Economic regulations" deal with activities such as mergers and acquisitions and price regulations. "Institutional regulations" manage areas like liability and IP, while "social regulations" cover environmental protection, workers' health and safety protection and, of most interest here, product and consumer safety (Blind, 2016, p. 452).

Innovation economist Knut Blind's review of studies of regulation and innovation in the US, Europe and several OECD countries reveals that the biotechnology and pharmaceutical industries are "traditionally heavily regulated". The key, he argues, is finding the balance between "flexible" regulations which promote innovation and "safety" regulations which promote public health and acceptance of new products and processes (Blind, 2016, pp. 460, 470, 474).

I mention this finding because it reflects the professional world in which most of my case study participants operate—medical science and technology. Blind agrees with participants that uncertainty of regulations and regulatory procedures, along with high compliance costs and delays related to the development and implementation of regulations are disincentives to investment in biotechnology R&D. They are, therefore, a barrier to innovation (Blind, 2016, p. 470).

Recognising the value of this observation and its relevance to participant comments, I recommend development of a flexible regulatory scheme for late-stage biotechnology developments, including medical devices and processes. As noted in the CSIRO's review of future opportunities for medical and pharmaceutical advances, a model exists which could be adapted (CSIRO, 2017, p. 63).

The so-called regulatory sandbox is an approach developed to boost the emerging financial technology industry. Very simply, it offers a "safe space" where firms or

[233] As Participant 8 noted, "So there's the inventing part of it, and there's then the regulatory side of it."

organisations can test and optimise products in a restricted environment before beginning the more complex, time-consuming and expensive process of industry-wide licensing. In return for a more flexible regulatory environment, players in the sandbox must provide safeguards in their testing models (CSIRO, 2017, p. 64; Hallatt et al., 2016).

The first regulatory sandbox scheme was introduced in 2015 in the UK. Since then, Hong Kong, Malaysia and Singapore have adapted the scheme to meet their requirements. In December 2016, the Commonwealth government welcomed the launch by the Australian Securities and Investments Commission (ASIC) of a regulatory sandbox for financial technology (Hallatt et al., 2016; Morrison, 2016).

Very simply, the scheme enables businesses to test a range of services with up to 100 retail clients and unlimited wholesale clients for up to 12 months without needing to apply for a license from ASIC. In return, firms are required to maintain consumer protections, including dispute resolution and compensation arrangements to ensure consumer safety.[234] As the CSIRO report states, this model is not directly applicable to medical technologies. I argue, nonetheless, that with further investigation it could provide a framework for them.

To that end, I recommend that the HSE Working Group begin the process of identifying and trialling a flexible regulatory regime by commissioning the CSIRO's strategic advisory and foresight arm, CSIRO Futures, to follow-on from their 2017 report and review of the possibilities offered by a regulatory sandbox for biotechnology.

Summary

In this chapter I offered 13 recommendations for enhancing the nation's ability to take potentially productive ideas from the laboratory to the market. Each recommendation responds to the barriers to innovation identified by my case study participants, and is shaped by my text analysis. They include an active role for government, as the sector of the innovation system with primary responsibility for funding and policy settings.

While much work has been done by academic scholars and independent experts, my recommendations add to this work in two ways. Firstly, and again, the problems they

234 See http://asic.gov.au/about-asic/media-centre/find-a-media-release/2016-releases/16-440mr-asic-releases-world-first-licensing-exemption-for-fintech-businesses/.

address were identified at the coal face, by the politicians, government officials and university researchers and industry representatives who contributed their ideas and experiences about the bionic eye initiative to my case study.

Secondly, my recommendations reflect the fact that the innovation system is just that, a system. I argue that a systemic approach to the complex and interrelated stumbling blocks to innovation is essential to overcoming the poor results the country has with maximising the fruits of its research. Given the limits imposed by Australia's three-year political cycle, change is difficult and uncertain. Having a clear overview, a system-wide view, of the problem is, however, a prerequisite to driving that change.

To that end, this chapter has presented a policy mix based upon themes derived from my case study. Each recommendation was contextualised based on existing national and international scholarship. The four themes are:

- A lack of *continuity* in Commonwealth policy, programs and structures.
- Inadequate and inefficiently managed *funding* for research and the innovation process.
- Poor levels of *collaboration* within and between the university and industry sectors.
- A difficult environment for research *translation*.

I offer my recommendations, not as a magic wand I would happily wave should one exist, but as an addition to the efforts by the many experts and scholars who also seek to remove the barriers hindering Australia's ability to maximise its innovative success.

Chapter 11: Conclusion

I began this intellectual journey as a former science journalist, frustrated by Australia's inability to maximise its research expertise. I ended it as doctoral candidate, optimistic that things can change, that my work does add to the body of knowledge about Australia's innovation system. My case study of the bionic eye has added fine-grained detail to the understanding of the structure and dynamics of Australia's science and innovation. Additionally, this thesis demonstrates the value of the National Innovation Systems model as a tool for analysing such systems.

The case study

The story of the Australian Research Council Special Research Initiatives Research in Bionic Vision Science & Technology – the bionic eye initiative -- provided a particularly appropriate case study. It has a clear beginning -- the 2008 announcement by the Rudd government that creation of an Australian bionic eye would be a national priority -- and a clear end in 2014, one that did not see the commercialisation of a product. Further, in May 2011 the Argus II retinal prosthesis, developed by California firm Second Sight Medical Products Inc., became commercially available in Europe (Dayton, 2011).[235]

Adding to the power of the case study, the bionic eye initiative involved the three fundamental arms of the nation's innovation system: The Commonwealth, government-funded research organisations and the private sector geared to the production and sale of scientifically oriented products. In terms of the National Innovation Systems framework, the initiative was system-wide. I was able, therefore, to obtain detailed information and insights from participants working across the innovation system. Most Australian case studies focus more narrowly on activities within one element of the innovation system.

Further, the lived experience of participants in the bionic eye initiative provided invaluable qualitative data that fleshed out existing analytical and descriptive texts and documents dealing with innovation in Australia, along with international assessments of

[235] See chapter 5 for details.

Australia's ranking on various measures of innovation success. The bionic eye initiative was, in sum, an unusually rich, extended case study.[236]

Finally, the history, structure and scope of the bionic eye initiative gives it applicability to other Australian programs and projects. The innovation barriers the case study reveals will be widely experienced by people working across the system. I hope that other researchers will extend my work.

The analytical framework

Given the system-wide nature of my case study, I chose to conduct what policy expert Charles Edquist calls a "diagnostic analysis" of my interview and text data. I was informed by the National Innovations Systems framework considered in Chapter 1, *The Concept of Innovation,* as I compared, contrasted and combined the qualitative results with those gained by reviewing texts and archival documents.

Central to this approach is the recognition that to obtain the most useful information about the operation of a science or innovation system – a construct established, run and experienced by people -- it is critical to derive data across the system. Policy and structures created and instituted without obtaining system-wide data are less likely to be productive than those based on a clear, evidence-based understanding of how the system operates, of its strengths and weaknesses and points of potential intervention.

Not only is the National Innovation Systems (NIS) model a useful tool for analysing the structure and operation of Australia's innovation system, it was especially valuable to me because few system-wide studies of the nation's innovation system have been conducted. Having access to an intellectual framework specifically designed for working with innovation systems enhanced the quality of my methodology and findings, by offering a guide for organising my thoughts and my data.

Specifically, I kept in mind the three domains of the NIS – a system's organisations, institutions and activities -- when gathering, analysing and presenting the data from my text-based research and qualitative data.[237] For instance, when formulating questions and interviewing participants I sought more than just their personal story of their involvement with the bionic eye initiative. I also wanted their views on the overall

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[236] See chapters 5-9 for findings of my participant interviews.

[237] See chapter 1 for a discussion of the NIS, its components

effectiveness of the nation's innovation system, their sector of the system and the interactions between the systems. My approach was systemic.

But not only was the NIS framework a valuable tool for structuring and conducting my personal research, my thesis demonstrates the value of the model as an analytical tool for investigating innovation in the Australian context. Although use of the framework is slowly growing in Australia, to date there is very little innovation system research conducted here in comparison to other Organisation for Economic Co-operation and Development nations. This became very clear to me when I attended the 2016 European forum for Studies of Policies for Research and Innovation General Conference in Lund. I was the only Australian delegate. I have not yet seen a comparable multi-national conference hosted anywhere in Australia. This thesis, therefore, makes an important contribution to Australian innovation research.

An unexpected advantage of my work is the demonstration that the NIS framework can be used effectively to derive theoretical lessons and insights from 'failed' innovation, that is from systems that perform below expectation given their social, political, intellectual and economic development. This is an important contribution to innovation system theory. This is the case because my exploration of the international innovation literature showed that NIS research focusses on learning from success stories such as those from Scandinavia, Japan and Israel.

Final thought

When I began considering the objectives of this thesis, a quote from Renaissance diplomat and writer Niccolo Machiavelli came to mind: "There is nothing more difficult to plan, more doubtful of success, nor more dangerous to manage than the creation of a new order of things".

I placed the quote at the beginning of my thesis. In the introduction I wrote that Machiavelli's advice to his prince is correct. Now, with the end of the project in sight, I am convinced more than ever that he was right.

Still, when it comes to enhancing Australia's ability to make the most of its scientific resources it is also now clear to me that there are places to intervene, steps to be taken, partnerships to be forged, outcomes to be boosted. Change is possible. I am convinced. It is possible to create a new order of things.

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Appendix 1: Key Policy and Review Documents 2001 to mid-2017

Abbreviations

AAD	Australian Antarctic Division
ABARES	Australian Bureau of Agricultural & Resource Economics & Sciences
AIATSIS	Australian Institute of Aboriginal & Torres Strait Islander Studies
AIMS	Australian Institute of Marine Science
ANSTO	Australian Nuclear Science & Technology Organisation
ARC	Australian Research Council
ARCom	Australian Research Committee
CCI	Coordination Committee on Innovation
CSIRO	Commonwealth Scientific & Industrial Research Organisation
CSTACI	Commonwealth State & Territory Advisory Council on Innovation
DSTO	Defence Science & Technology Organisation
EIF	Education Investment Fund
GA	Geoscience Australia
NHMRC	National Health & Medical Research Council
PFRAs	Publicly Funded Research Agencies

Learned Academies: Australia Academy of Science, Australian Academy of Technological Sciences & Engineering, Australia Academy of Social Sciences, Australian Academy of Humanities

INTRODUCTION

Since the turn of the 21st Century there are have been dozens of science and innovation documents and reports produced by and for Australia's successive Federal governments. What follows is a list, in chronological order, of documents of most relevance to this thesis. I have selected documents which represent the most coherent presentation of the government of the day's approach to science and innovation, along with independent and government-conducted reviews. There are chronological gaps in which no significant policy work was conducted. Interest in science and innovation, ebbs and flows between and within governments.

It's important to note that while many of the components of the science and innovation system remain, for example, the National Health & Medical Research Council and the Australian Research Council, priorities shift as do governments. The result is that the amount of funding to elements of the system will change, and programs to deliver on priorities come and go. I have included a graphic at the end of this appendix which shows the basic components of Australia's science system.

The following list begins in 2001 and runs to 2017. In compiling the list I wish to acknowledge the assistance of Alexander Cook of the Department of Industry, Innovation and Science's Science Policy Team.

BACKING AUSTRALIA'S ABILITY (2001) Howard Government Policy Statement

BAA is a five-year innovation strategy which commits $2.9 billion over five years to fund initiatives to stimulate research and innovation. The initiatives were guided by the Science & Innovation Ministerial Council, headed by the Prime Minister, and the Chief Scientist. New initiatives focus on tax concessions for research and development (R&D). Additional funding is provided to the Australian Research Council (ARC) Discovery and Linkage competitive grants. Funding is also allotted to research and university infrastructure, collaborative hubs like Cooperative Research Centres (CRCs) and Centres of Excellence, as well as to Science, Technology, Engineering & Mathematics (STEM) initiatives in public schools and at universities.

BACKING AUSTRALIA'S ABILITY: Building our future through science & innovation (2004) Howard Government Policy Statement

Known as **BAA2**, the policy document builds on BAA and identifies science and innovation as one of the Government's "strategic policy priorities". It commits an additional $5.3 billion over 10 years. It incorporates ideas from the 2003 **Mapping Australian Science & Innovation**[238] review of policy and program evaluations. BAA2 focusses on infrastructure – through the new National Collaborative Research Infrastructure Strategy (NCRIS) – and commercialisation, through Commercial Ready grants. It provides additional funding for the National Health & Medical Research Council (NHMRC*),* the Commonwealth Scientific and Industrial Research Organisation (CSIRO) National Research Flagships, and for the Commercialising Emerging Technologies initiative. It announces a research quality assessment mechanism, then called the Research Quality Framework.

NCRIS STRATEGIC ROADMAP (February 2006) Howard Government Policy Statement

This document, known as the **Strategic Roadmap,** fleshes out the priorities for Australia's investment in research infrastructure through NCRIS, as announced in **BAA2**. Headed by university administrator Rory Hume, the NCRIS advisory committee based its recommendations on written submissions and consultations with "stakeholders". It established six underpinning principles, the first of which is that NCRIS should aim to maximise federal contributions of the R&D system to national security and the economic, environmental and social wellbeing of the nation. The roadmap says infrastructure resources should be focussed on areas where Australia has, or could have, an international scientific advantage. Thirty such "capability areas" are identified. Among them: bioinformatics, animal models of disease, translating health discovery to clinical application, population health, biosecurity, astronomy, and computing and communications networks. The roadmap is to be updated periodically to reflect changing priorities and the emergence of new opportunities.

VENTUROUS AUSTRALIA: Building strength in innovation (August 2008) Rudd Government Review

Known as **The Cutler Review**, for its chair Terry Cutler, Venturous Australia is an independent review of Australia's science and innovation system. The concept of "innovation" is not explicitly defined. The review states that innovation is "far more" than funding R&D, commercialisation, and the creation of new products or processes.

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[238] I did not summarise this document separately as BAA2 is more comprehensive and plucks its key elements.

Innovation includes "operations, organisation, relationships and business models". Emphasis is placed on the role of government in innovation through support for infrastructure and public research. The review received over 700 submissions, conducted a series of roundtable seminars, and made 72 recommendations. Recommendations centre on innovation in business, strengthening innovation managerial skills, revision of the R&D tax system, promotion of excellence in national research, and knowledge flows. The recommendation regarding the R&D tax system was the only one adopted. In his 2009 Pearcey Foundation Oration speech[239] Cutler said, "Reviewing our recent innovation performance does not inspire confidence in Australia's future". He highlighted stalled productivity growth, an "intellectual property trade deficit", and the worst level of international collaboration in the Organisation for Economic Co-operation and Development (OECD).

STRATEGIC ROADMAP FOR AUSTRALIAN RESEARCH INFRASTRUCTURE (August 2008) Rudd Government Report

This report highlights the importance of research infrastructure to advances in science and innovation. It builds on the Howard Government's 2006 **Strategic Roadmap** and sets out the government's major national and systemic infrastructure investment priorities, as well as arrangements for the assessment and implementation of landmark infrastructure projects. Central to both roadmaps is the role of NCRIS in funding infrastructure projects designed to encourage collaborative use of research infrastructure, instruments and policy initiatives. Priority research areas to be supported are identified, among them optical and radio astronomy, biosecurity and pre-clinical testing. The report does not announce funding to support the roadmap.

POWERING IDEAS: An innovation agenda for the 21st Century (2009) Rudd Government Policy Statement

The policy statement sets out the government's 10-year innovation strategy, backed by an $8.58 billion investment in science and innovation. It builds on the 2008 **Strategic Roadmap, r**esponds to **The Cutler Review,** and reflects aspects of National Innovation Systems thought.[240] It states that when markets fail it is the role of government to "plug gaps" to prevent the loss of knowledge and innovations. This would be accomplished by building a more integrated innovation system in which public agencies, universities and industry collaborate. Major initiatives include additional funding for research infrastructure and indirect university research costs, postgraduate stipends and mid-career research fellowships. Changes are outlined to university funding and to R&D tax incentives. Powering Ideas also establishes a set of National Innovation Priorities, essentially goals, to complement the government's set of National Research Priorities. Among these are increased international collaboration by Australian universities, a 25% increase in industry R&D, and an increase in the number of publicly-funded research groups operating at the international level.

STRATEGIC ROADMAP FOR AUSTRALIAN RESEARCH INFRASTRUCTURE (2011) Gillard Government Policy Statement

Like the 2006 and 2008 **Strategic Roadmaps** the 2011 document underscores the need to support the national research effort by investing in essential equipment, facilities and services such as the Australian Research and Education Network, a system which

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[239] For a summary of the oration see http://ict-industry-reports.com/2008/09/12/national-innovation-review-cutler-report-released-venturous-australia/

[240] See chapter 1 for a discussion of the National Innovation Systems framework.

connects universities, research agencies in cities and regional areas, and isolated facilities such as radio telescopes. Shared use of the infrastructure is required. It lists 19 research areas for investment. These focus on the environment and sustainable energy, health and population studies, together with astronomy, materials fabrication and cyber and biological security. Funding levels are not announced, but it is noted that NICRIS is the primary funding body.

RESEARCH SKILLS FOR AN INNOVATIVE FUTURE (2011) Gillard Government Policy Statement

This statement compliments the 2011 **Strategic Roadmap** by providing an overview of the strengths and weakness in the research workforce of the day. It sets workforce priorities. Among these is the need to provide better career pathways, skills, and support for research graduates. Another is the need to ensure adequate numbers of research-qualified individuals in public research institutions and universities to meet national priorities, as well as enough to work in and with business. The document, based on 18 months of consultation and research, notes there is limited data on some characteristics of the research workforce, such as longitudinal data on research careers. The government says it will take steps to rectify the data "gaps".

NATIONAL RESEARCH INVESTMENT PLAN (2012) Gillard Government Policy Statement

This Plan takes an overview of Australia's system of innovation and research. It seeks to build a knowledge-based economy able to compete in "the Asian Century", one ranked among the top 10 of innovative nations. (In 2013 Australia ranked 19th on the Global Innovation Index; in 2016 it ranked the same.[241]) It is intended to be the first in a series of three-year plans. The Plan builds on earlier documents, including **Powering Ideas (2009)**, **Strategic Framework for Research Infrastructure Investment (2010)**, **Research Skills for an Innovative Future (2011)**, and **Australia in the Asian Century (October 2012).** The Plan was developed by the Australian Research Committee, chaired by the Chief Scientist, after consultation with federal, state and territory governments, along with industry and public and private research organisations. The statement recognises that research and innovation policy and funding commitments shift over time. It sets out a national research investment framework and process to enable governments to meet new challenges while maintaining continuity with the existing research and innovation system. This framework comprises a coordinated, whole-of-government approach to research and innovation investment. It takes in government objectives, national research capacity, investment principles and research priorities.

STRATEGIC REVIEW INTO HEALTH & MEDICAL RESEARCH (2013) Gillard Government Review

Known as **The McKeon Review,** for its chair Simon McKeon, this independent review concludes that although Australian health and medical researchers are prolific and their work is "relatively highly cited" in journal publications, it is not translated into evidence-based clinical and health interventions at a level comparable to other developed nations. The review – based on consultations with researchers, clinicians, hospital managers and state and territory governments – calls for initiatives to increase the collaboration necessary to overcome this deficiency. It states that increased funding

[241] These rankings are based on multiple metrics such as a nation's politic environment, education system, market sophistication, knowledge creation and so forth. As such, they generally rise and fall gradually for OECD countries, including Australia.

to the health system and the NHMRC is a first step. The funding would support immediate establishment of a set of 8 to 10 national health research priorities and an expert committee for each area. The review presents a 10-year strategy containing 21 detailed recommendations designed to strengthen the connections between researchers and health professionals. Among these are recommendations to invest at least 3% of federal, state and territory health expenditure on R&D within the health system, to establish Integrated Health Research Centres combining hospital networks, universities and medical research institutes to drive translation of research into clinical practice, and to improve research career paths. None of the recommendations were adopted by the Gillard or Rudd Governments.

AUSTRALIAN INNOVATION SYSTEM REPORT (2013) Rudd Government report

This is the fourth in a series of annual reports on the performance of Australia's national innovation system. It discusses the importance of innovation to society and the economy and measures the system's performance against that of other leading nations using a range of international metrics. It closely examines the level of integration of Australia's economy with the rest of Asia, building on the **National Research Investment Plan (2012)** which stresses the importance of scientific and business integration with Asia. It emphasises the importance of "innovative" environmental goods and services to the Asian market. The report's methodology is based on the concept of "diagnostic analyses" as described by Swedish innovation expert Charles Edquist.[242] Major conclusions are that Australia's innovation system is not as efficient as those of high-performing nations, and the country relies heavily on Europe and the US for new knowledge, investment, technology and innovation.

NATIONAL INNOVATION AND SCIENCE AGENDA (2015) Turnbull Government policy statement

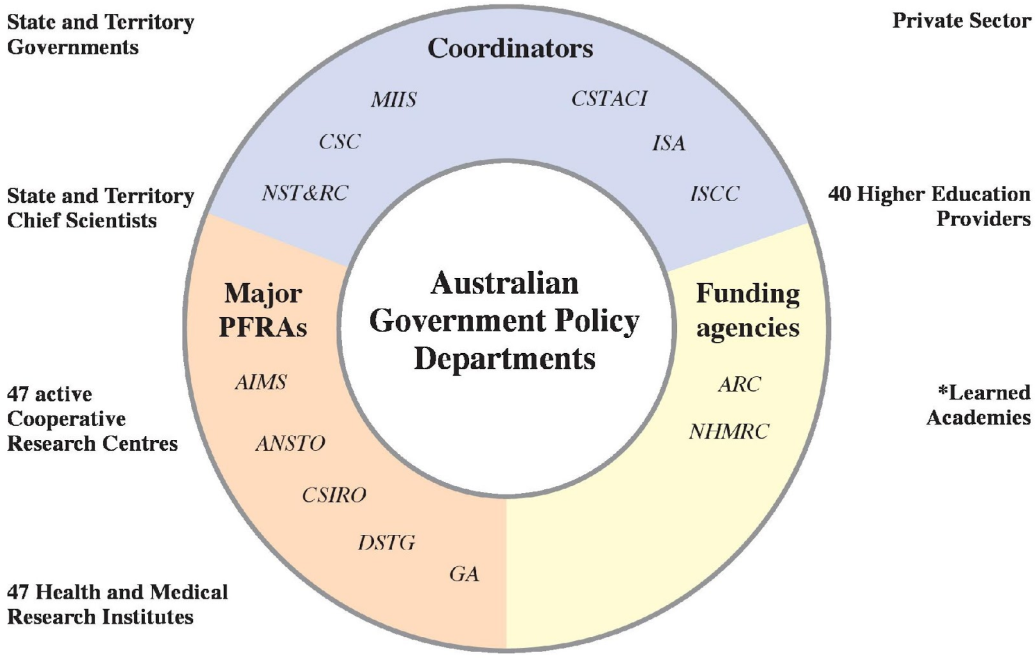
During his tenure as Prime Minister (2013-2015), Tony Abbott's government released only one science or innovation policy statement, its business-oriented 2014 *Industry, Innovation and Competitiveness Agenda.* Controversially, Abbott failed to appoint a science minister for over a year. When Malcolm Turnbull replaced Tony Abbott as Prime Minister in September 2015, he promised to put "innovation and technology'' at the centre of his government. Turnbull's signature *National Innovation and Science Agenda* (NISA), released the following December has remained the framework for his government to date. Although there is a heavy focus on support for industry, it also recognises the value of boosting collaboration between the publicly-funded research and private sectors, and encouraging students to enter the fields of science, technology, engineering and medicine. Numerous initiatives have been established to meet these goals.

[242] The report contains a short feature by Charles Edquist at Sweden's Lund University. The feature is called *Comparing National Innovation Systems of Innovation Policy Purposes* and is based on Edquist, C, 2011 which is cited in Chapter 1 of this thesis.

AUSTRALIA'S SCIENCE SYSTEM

AUSTRALIA'S INNOVATION SYSTEM

The interactions between policy makers and decision-makers and the science community are complex. Figure 4 provides a visualisation of the organisation of key actors within the Australian Science System. Government, through departments and funding agencies, provides the funding and support to underpin the science system. Within the system there are numerous science suppliers, including PFRAs, universities, CRCs and H&MRIs, which receive significant amounts of government funding. Government departments also have established formal relationships with coordination bodies and funding agencies.



NST&RC	National Science Technology & Research Council (operational arm of CSC)
CSC	Commonwealth Science Council (chaired by Prime Minister)
MIIS	Ministry of Industry, Innovation & Science
CSTACI	Commonwealth State & Territory Advisory Council on Innovation
ISA	Innovation & Science Australia
ISCC	Innovation & Science Committee of Cabinet (chaired by Prime Minister)
ARC	Australian Research Council
NHMRC	National Health & Medical Research Council
PFRAs	Publicly Funded Research Agencies
AIMS	Australian Institute of Marine Science
ANSTO	Australian Nuclear Science & Technology Organisation
CSIRO	Commonwealth Scientific & Industrial Research Organisation
DSTG	Defence Science and Technology Group
GA	Geoscience Australia

**Learned Academies: Australia Academy of Science, Australian Academy of Technological Sciences & Engineering, The Academy of the Social Sciences in Australia, Australian Academy of THE Humanities*

Sources: ABARES (Australian Bureau of Agricultural & Resource Economics & Sciences) and personal communications.

SOURCE: APS200 Project, 2012, p. 3

NB: As of 2014 there were 36 active CRCs; 44 health & Medical Research Institutes; and 40 Higher Education Providers

Appendix 2: Senate Submission

Department of Philosophy
MACQUARIE UNIVERSITY NSW 2109
AUSTRALIA
Phone +61 (0)2 9850 8837
Fax +61 (0)2 9850 8892
Email philosophy@mq.edu.au

Senate Standing Committee on Economics
PO Box 6100
Parliament House
Canberra, ACT, 2600

Economics.sen@aph.gov.au

RE: Submission to the Inquiry into Australia's Innovation System

Dear Secretariat:

I'm writing to you wearing two hats: one as a Macquarie University doctoral student, exploring innovation pathways in Australia. The other is as a science writer and broadcaster with over 20 years' experience in Australia. The latter triggered the former.

From my earliest days in Australia – I'm from California via Canada -- it was clear that while the country conducts high quality fundamental research in fields like medicine, astronomy and geology, when it comes to taking potentially commercial products and processes to market, the nation has a very poor record, indeed.

The Global Innovation Index[243] makes this point clear. While Australia has moved up the rankings from 19th place in 2013 to 17th in 2014, the country is outclassed by developmentally comparable medium and small nations, including Switzerland, Finland, Germany, Canada and the Asian states of South Korea, Hong Kong and Singapore. We have, however, jumped ahead of New Zealand since 2013.

Having investigated the evolution of Australia's scientific and innovation system from colonial days to the present, it's obvious that there are fundamental reasons why we punch below our weight. I argue that while these reasons – obstacles to successful innovation – are deeply embedded in Australia's political, economic and intellectual culture, they can be tackled with informed policy actions. I was pleased to read that the issue of policy actions is highlighted in the inquiry's Terms of Reference.

Please note that I'm focussing here on innovation at the national level, as opposed to private sector innovation. As well, I define innovation as a process, not an invention, and use the OECD's conceptualisation of a "national innovation system" as the network of public and private institutions which generate, import, modify and diffuse new products or processes.[244]

243 See www.globbalinnovationindex.org

244 OECD, *National Systems of Innovation*, 1997. www.oecd.org/science/inno/2101733

I hope the following observations will be of value to your review and recommendations, especially when combined with submissions that are geared towards specific elements of the nation's innovation system, for instance higher education or university research.

Australia's innovation system is a historical relic

The nation's innovation system grew on an ad hoc basis, depending upon political and economic circumstances of the day. Given that the nation's original economic role was as a colonial supplier of agricultural and mineral resources, it's not surprising that those areas of expertise were preferentially bolstered over time by the creation of federal research bodies. The process began after federation with the founding in 1916 of the Commonwealth Serum Laboratories – privatised in 1994 –and in 1926, the Council for Industrial Research, now the Commonwealth Scientific and Industrial Research Organisation.

Over time, additional federal research organisations were added and restructured, tariffs added and removed, and federal involvement in innovation expanded, resulting in today's network of agencies, federal departments, learned academies, and coordinating bodies and advisors, including the office of the Chief Scientist. Connections to the private sector ebb and flow, forming the system in which innovation occurs.[245]

Lack of continuity

Since the first major bi-partisan efforts in the 1980s to rethink and enlarge the federal role in both science and innovation, each succeeding government has established its own priorities, cutting, renaming, or adding projects, committees and agencies, as well as shifting funding up or down, depending upon its political views.

There have been numerous policy statements and reviews, the outcomes of which are variable.[246] The most well-known of the independent reviews are the so-called Cutler Review (2008) and the McKeon Review (2013). In personal communications, both Cutler and McKeon say none of their recommendations were adopted.

Broadly, both focussed on continuity of funding, a strong federal role in innovation and coordinated linkages between research and the private sector, with McKeon directing his recommendations to the health sector. Given the lack of uptake, these reviews were a complete waste of time and money.

Not fit for purpose

As Australia moves into the 21st Century, it is lumbered with a poorly designed national innovation system with equally poorly developed and directed policies which rely heavily on free market solutions. Unfortunately, this approach is failing to maximise the nation's intellectual expertise. It's often said that when it comes to research and development, Australia is all "R" and no "D". That is, industry seldom adopts or commercialises new ideas or products from the research sector, compared to other nations worldwide.

Also hampering the effective exploitation of Australia's brainpower is an economic system consisting primarily of small companies with a low propensity to innovate and export, along with a small domestic market. The country still relies heavily on the export of agricultural and mineral resources – which command ever-decreasing prices in the global marketplace.

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[245] See attached Appendix.

[246] See Appendix.

There are few large, home-grown high technology firms. Australia's largest hi-tech firms are generally subsidiaries of international corporations.[247]

Innovation is further hampered by the fact that when compared with international competitors such as those highlighted by the GIobal Innovation Index, Australian business management capability and innovation culture is weak.[248]

Similarly, many federal policy makers, managers and federal politicians have a limited grasp of the processes of science and innovation. This is reflected in the recent cutbacks to science funding. Terry Cutler speaks for many experts when he says, "Science and technology capability is not something you can turn off and on like a tap".

Finally, Australia's venture capital sector is small and risk averse. It's telling that the country imports four times as much intellectual property than it exports. As University of Queensland innovation expert Mark Dodgson says, "If you're not at the forefront you have to pay the premium prices that create trade deficits".[249] Effectively, Australia sells low and buys high.

Getting it right

Every country is unique. Still, there is much Australia can learn much from the experiences of successful innovative nations that consistently beat us in the Global Innovation Index ratings. Some suggestions follow which are based on my observations and successful international experience.

Bury the political hatchet

As Cutler suggests, chopping and changing support for innovation doesn't work. Highly innovative small- and medium-sized nations have identified national areas of advantage and strategically support them, regardless of changes to political leadership. Australia could do the same.

As noted above, much work has already been done in this regard. An independent committee of experts, headed by the Chief Scientist, could review the recommendations of existing reviews and bring the information to the government for bi-partisan discussion and action.

Areas of national excellence include: biomedical research and agricultural and resource technologies.

A consistent and strategic vision for innovation is critical. At present, Australian innovation policy lacks direction, but is brimming with motherhood statements such as "support for the best and brightest" or "innovation is the driver of the economy". Nice, but useless.

Support the process not the player

Countries like Finland, Singapore, Germany and Sweden follow what's known in innovation circles as the National Innovation Systems framework. That is, they have created

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247 Among others see, Green, R, and Logue, D, "Innovation Australia: How we measure up", in *Australia Adjusting: Optomising national prosperity,* 2013, CEDA; Dodgson, M, "Innovation in Australia – getting to where we want to be", 9 February 2013, ABC Radio National, *The Science Show.*

248 See Green and Logue, and Dodgson above.

249 See Dodgson above.

systems that are consistent across governments. The systems ensure that government research institutions work closely with private business to co-fund the innovation process: from bright idea to commercialised product or process. They have designed systems that, in a nutshell, consist of:

- A council of independent experts who regularly advise the national leader on innovation policy. This group has oversight of the innovation system. Membership does not change after national elections. In Australia, the PM's Science & Engineering Council could be beefed up to perform this role, co-chaired by the Chief Scientist and a dedicated Science Minister. At present, Australia does not have a Science Minister.

- Strategic agencies that support basic research and commercialisation. Not only are these agencies responsible for funding in their areas, they work as collaborators with applicants – small to large, private and public – to develop their project and identify and resolve technical and interpersonal difficulties as they arise. As a report for the UK Innovation Foundation states:

  "Simply backing academic research or bright start-ups and hoping that they will reach commercial maturity at home is a risky tactic in a small country with fewer larger businesses and a smaller local market.[250]

The Australian Research Council and the National Health & Medical Research Council could be given clear mandates and consistent funding to reshape their activities. It is important that they bring in overseas experts to assist with funding decisions and advise on their own performance.

Support collaboration: local, national & international

No country, business or research agency has a monopoly on good ideas. Australia has not managed collaboration effectively. For instance, Australia was ranked 28th in the OECD for collaboration among large firms and 27th for collaboration among small to medium-sized enterprises.

It is, therefore, important that existing programs which promote collaboration between research agencies and businesses, such as the Co-operative Research Centre Program and National ICT Australia (NICTA), be bolstered and provided with consistent multi-year funding. Unfortunately, NICTA will not be funded beyond 2015-2016.

Further, programs to place researchers into business should be encouraged, as suggested for the health sector in the McKeon Report. Australia does this badly. In the US, for example, most of the nation's engineers work in private industry. In Australia, they work in research agencies.

Linkage (ARC) and Partner (NHMRC) grant programs are successful initiatives and should be supported to break down this research-industry divide. Businesses with international R&D connections should be encouraged to collaborate with the research community through appropriate taxation and other mechanisms.

Similarly, programs and scholarships which promote international collaboration should be enhanced. The Australian Laureates Fellowship program has been successful in ensuring

[250] Rae and Westlake (2014). Other relevant publications include Roos and Gupta (2004) and Edquist and Hommen (2008).

leading experts are encouraged to work here or, as in the case of Nobel Prize winning immunologist Peter Doherty, bring their expertise home.

It is positive that Industry Minister Ian Macfarlane has flagged action to build on the former Labor government's plan to establish a series of innovation precincts around the country. The approach could also fold-in the highly successful “Smart State Strategy”, pioneered by the Queensland government in the mid-2000s.

Embed innovation across the government

As Rae and Westlake note, nations that innovate well, not only support innovation directly through funding, they promote it through their wider activities.

This starts with a dedicated Science Minister who has a handle on innovation-related activities across the various portfolios. The minister would be a key point of contact for the Chief Scientist and the Prime Ministerial advisory council as discussed above, as well as for private industry.

Successful innovating nations also promote the use of innovative products and services within the government. An example is Estonia which adopted home-grow digital technologies across its public services. Another strategy is preferential purchasing. It is of concern that high-tech industries such as the automotive and submarine industries have not been, or potentially will not be supported for government purchases.

Conclusion

Thank you for initiating this review and inviting submissions. And thank you for reading this far! The ideas I’ve covered are broad, but I hope helpful.

As a journalist I watched while the innovation wheel was reinvented with each new government, while great ideas died in the innovation “Valley of Death” or were developed abroad, while Australia made strides to improve its approach to innovation, only to slip back as a result of short-term political decisions and lack of a strategic vision.

As a doctoral student I want to make a contribution to what I hope will be a much welcomed report that makes informed recommendations which see the light of political and practical day.

Thank your for your attention.

I remain,

Sincerely yours,

Leigh Dayton
Science Writer & Broadcaster
PhD Candidate Macquarie University
Leigh.Dayton@students.mq.edu.au

Appendix 3: Bionic Eye Timeline

TIMELINE:

1751: Benjamin Franklin discovers electricity

1753: Charles LeRoy runs electrical current between a man's leg and head & produces phosphenes

1800: Alessandro Volta applies current to eye and produces phosphenes

1929: Otfrid Foerster stimulates occipital lobes of brain & produces phosphenes

1931: Fedor Krause & H. Schum confirm Foerster's findings

1956: Graham Tassicker patents first bionic eye

1968: G.S.Brindley & W.S. Lewis stimulate visual cortex and produce phosphenes corresponding to eye movement

1974: William Dobelle & M.G. Mladejovsky report series of experiments stimulating occipital lobe to produce phosphenes

1990 & 1996: M.J. Bak & E.M. Schmidt publish reports, advancing both Dobelle's & Brindle's work. Now collaborate with IVP

1992: Humayum, de Juan & Howard Phillips granted US patent on retinal prosthesis

1996: Humayun, Greenberg, de Juan, et. al. report producing phosphenes by stimulating retinas of blind patients

1998: Sydney group publishes first paper, a review of the field

1998: Robert Greenberg co-founds Second Sight Medical Products Inc with Al Mann

1998: MiVip group reports volunteer with optical nerve implant perceives shapes, line orientations & letters

2004: Dobelle dies. Patent on the 'Dobelle eye' donated to Stony Brook University in New York.

2004: C-Sight founded

2004: POW group reports first animal experiments with visual cortex prosthesis

2005: Coroneo, Chowdhury & Morley file US patent on extraocular prosthesis. Granted 2011

2006: Suaning, Lovell & Kerdraon awarded US patent on retinal prosthesis*

2008: POW group ready to trial epiretinal (on sclera) prosthesis

2008: Rudd Government holds Australia 2020 Summit, announces Bionic Eye as a national initiative

2009: Science Minister Kim Carr & Health Minister Nicola Roxon announce $50.7million Bionic Eye funding

2009: BVA wins $42million of four years. MVA wins $8 million over four years.

2011: Second Sight receives CE Mark in Europe to market Argus II

2011: Pixium Vision founded.

2013: Rizzo and Wyatt found spin-off company Bionic Eye Technologies

2013: RI receives CE Mark in Europe to market Alpha IMS system

2013: Second Sight receives US FDA approval to market Argus II

2013: BVA awarded $8million and MVG $1.9million funding extension

2014: BVA announces completion of two-year trial of prosthesis with 3 patients

2015: Argus II first used for age-related macular degeneration

2015: Bionic Vision Technologies (commercial arm of BVA) seeks $10 million for further trials of epiretinal prosthesis

2015: MVA reports at conference on preclinical trials ahead of human trail in 2016 or 2017.

2015: MU forms iBIONICS with Canadian entrepreneurs to ready BVA's high-acuity epiretinal implant for human trial.

2016: MVA raises funds to support human trial in late 2017.

2016: BVA team readies revised suprachoroidal prototype for human trial in 2017.

2016: Pixium Vision begins multi-centre clinical trial of IIRIS II epiretinal prosthesis.

2016: Pxium Vision obtains CE Mark in Europe to market IRIS II.

**By 2016 The UNSW and POW Groups and later BVA and MVA had applied for or received several patents.*

Appendix 4: Bionic Eye Players

KEY PLAYERS:

USA

Second Sight Medical Products, Inc.: Robert Greenberg (CEO).
Target: Eye (retina). Collaborates with Doheny Retina Institute.

Doheny Retina Institute at USC: Mark Humayun (associate director) collaborated with and succeeded Eugene de Juan now with ForSight Labs.
Target: Eye (retina).

ForSight Labs: Eugene de Juan (vice-chairman).
Target: Eye (retina).

Boston Retinal Implant Project: Joseph Rizzo & John Wyatt (founders).
Target: Brain.

Intracortical Visual Prosthesis (IVP) group: Philip Troyk (team leader).
Target: Brain.

University of Utah group: Richard Normann (team leader).
Target: Brain. Developing the Utah Electrode Array.

EUROPE

Microsystems-Based Visual (MiVip) consortium: Claude Veraat (team leader).
Target: Optic nerve. Active 1996-2000.

Optimization of the Visual Implantable Prosthesis project (OPTIVIP): Claude Veraat (team leader).
Target: Optic nerve. Active 2001-2005. Work continuing at Veraat lab at the Universite' Catholique de Louvain & China.

Retina Implant AG (RI): Eberhart Zrenner (founder & chair of supervisory board).
Target: Eye (retina).

Pixium Vision: Bernard Gilly (founder & chair).
Target: Eye (retina).

CHINA

Chinese Project for Sight (C-Sight):
Target: Optic nerve. Modifying the MiVip-OPTIVIP design.

AUSTRALIA

Sydney Group: Minas Coroneo, Vivek Chowdhury, Jim Morley, Jim Patrick, Gregg Suaning.
Target: Visual cortex & eye (outside sclera). Splits into two groups.

University of New South Wales Group (UNSW): Gregg Suaning & Nigel Lovell.
Target: Eye (retina). Joins Bionic Vision Group.

Prince of Wales (POW) Group: Minas Coroneo and Vivek Chowdhury.
Target: Eye (on sclera). Eventually disbands.

Bionic Vision Australia (BVA): Anthony Burkitt (director), David Penington (chairman until 2013), Mark Hargreaves (chairman).
Target: Eye (retina).

Monash Vision Group (MVG): Anthony Lowery (director), Jim Patrick (advisory board), David de Kretser (chairman).
Target: Visual cortex.

Appendix 5: Ethics Approval

MACQUARIE University
SYDNEY·AUSTRALIA

From: **Ethics Secretariat** <ethics.secretariat@mq.edu.au>
Date: Mon, Jul 22, 2013 at 11:59 AM
Subject: Approved - Ethics Application REF 5201300423

To: Prof Wendy Rogers <wendy.rogers@mq.edu.au>

Dear Professor Rogers

RE: "Australia's quest for the Bionic Eye and the politics of innovation"

(REF: 5201300423)

Thank you for your email dated 14 July 2013 responding to the issues raised by the Macquarie University Human Research Ethics Committee (HREC (Medical Sciences)).

The HREC (Medical Sciences) is fully constituted and operates in accordance with the National Health and Medical Research Council's National Statement on Ethical Conduct in Human Research (2007) (the National Statement) and the CPMP/ICH Note for Guidance on Good Clinical Practice.

I am pleased to advise that the above project has been granted ethical approval, effective 22 July 2013.

This research meets the requirements of the National Statement which is available at the following website: http://www.nhmrc.gov.au/_files_nhmrc/publications/attachments/e72.pdf

This letter constitutes ethical approval only.

The following documentation has been reviewed and approved by the HREC (Medical Sciences):

1. Macquarie University Ethics Application Form (v. 2.1 - Feb 2013)
2. Macquarie University Participant Information and Consent Form- "Australia's quest for the bionic eye and the politics of innovation" (no version number/undated)
3. Correspondence from Professor Rogers (dated 14 July 2013)
4. Recruitment Email text - direct contact (no version number/undated)
5. Recruitment Email text - referral (no version number/undated)
6. Questions for politicians (no version number/undated)
7. Questions for policy makers (no version number/undated)

Please note the following standard requirements of approval:

1. The approval of this project is conditional upon your continuing compliance with the National Statement. It is the responsibility of the Principal Investigator to ensure that the protocol complies with the HREC-approval and that a copy of this letter is forwarded to all project personnel.
2. The National Statement sets out that researchers have a "significant responsibility in monitoring, as they are in the best position to observe any

adverse events or unexpected outcomes. They should report such events or outcomes promptly to the relevant institution/s and ethical review body/ies, and take prompt steps to deal with any unexpected risks" (5.5.3). Please notify the Committee within 72 hours of any serious adverse events or Suspected Unexpected Serious Adverse Reactions or of any unforeseen events that affect the continued ethical acceptability of the project.

3. Approval will be for a period of five (5) years subject to the provision of annual reports. NB. If you complete the work earlier than you had planned you must submit a Final Report as soon as the work is completed. If the project has been discontinued or not commenced for any reason, you are also required to submit a Final Report for the project. Progress reports and Final Reports are available at the following website: http://www.research.mq.edu.au/for/researchers/how_to_obtain_ethics_approval/human_research_ethics/forms
4. If the project has run for more than five (5) years you cannot renew approval for the project. You will need to complete and submit a Final Report and submit a new application for the project. (The five year limit on renewal of approvals allows the Committee to fully re-review research in an environment where legislation, guidelines and requirements are continually changing, for example, new child protection and privacy laws).
5. All amendments to the project must be reviewed and approved by the Committee before implementation. Please complete and submit a Request for Amendment Form available at the following website: http://www.research.mq.edu.au/for/researchers/how_to_obtain_ethics_approval/human_research_ethics/forms
6. At all times you are responsible for the ethical conduct of your research in accordance with the guidelines established by Macquarie University. This information is available at the following websites: http://www.mq.edu.au/policy/http://www.research.mq.edu.au/for/researchers/how_to_obtain_ethics_approval/human_research_ethics/policy

If you will be applying for or have applied for internal or external funding for the above project it is your responsibility to provide the Macquarie University's Research Grants Management Assistant with a copy of this email as soon as possible. Internal and External funding agencies will not be informed that you have ethics approval for your project and funds will not be released until the Research Grants Management Assistant has received a copy of this email.

If you need to provide a hard copy letter of ethics approval to an external organisation as evidence that you have approval please do not hesitate to contact the Ethics Secretariat at the address below.

Please retain a copy of this email as this is your official notification of ethics approval.

Yours sincerely

Dr Karolyn White

Director of Research Ethics Chair, Human Research Ethics Committee (Medical Sciences)
Ethics Secretariat Research Office
Level 3, Research Hub, Building C5C East
Macquarie University NSW 2109 Australia

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http://www.mq.edu.au/research

Appendix 6: Information and Consent Form

Supervisor's Name: Professor Wendy Rogers
Supervisor's Title: Professor of Clinical Ethics

Information and Consent Form

Name of Project: Australia's Quest for the Bionic Eye & the Politics of Innovation

You are invited to participate in a study of the pathways of biomedical innovation in Australia. The purpose of the research is to identify the organisational and cultural factors that enhanced or impeded the bionic eye initiative announced in 2008 by then Prime Minister Kevin Rudd.

The study is being conducted by Leigh Dayton of the Research Centre for Agency, Values & Ethics within the Department of Philosophy, Faculty of Arts (leigh.dayton@students.mq.edu.au; Ph 0411-2-444-28) in order to meet the requirements of a Doctor of Philosophy. The work is being done under the supervision of Professor Wendy Rogers (Ph 02-9850-8858; wendy.rogers@mq.edu.au) and Dr Katrina Hutchison (Ph 02-9850- 6772; katrina.hutchinson@mq.edu.au) of the Philosophy Department, as well as Dr Lisa Wynn (Ph 02-9850-8095; lisa.wynn@mq.edu.au) of the Anthropology Department.

If you decide to participate you will be asked to recall your participation in the bionic eye initiative. The interview should take no longer than 45 minutes and will be conducted over the telephone at a time convenient for you or, if necessary, at your workplace. The interview will be audio-recorded for later transcription and analysis.

Unless you permit the use of specified quotes, any information or personal details gathered in the course of the study are confidential *(except as required by law)*. No individual will be identified in any publication of the results unless they have agreed to be identified. The interview tapes and transcripts will be kept by the student and only she and her supervisors will have access to them. A summary of the results of the data can be made available to you upon request.

Participation in this study is entirely voluntary. You are not obliged to participate and if you decide to do so you are free to withdraw at any time without having to give a reason and without consequence.

The ethical aspects of this study have been approved by the Macquarie University Human Research Ethics Committee (Approval #5201300423). If you have any complaints or reservations about any ethical aspect of your participation in this research, you may contact the Committee through the Director, Research Ethics (telephone [02] 9850 7854, fax [02] 9850 8799, email: ethics@mq.edu.au). Any complaint you make will be treated in confidence and investigated, and you will be informed of the outcome.

The participant has been given a copy of this information and consent form to keep.

"I agree to participate in this research.

"I agree / do not agree (circle one) to be quoted using a pseudonym / using my real name (circle one) in any write-up of the research results."

Participant ___________________ Signed _______________________ Date _________

Investigator __Leigh Dayton ____ Signed _______________________ Date _________

(INVESTIGATOR'S [OR PARTICIPANT'S] COPY)

Appendix 7: Bionic Eye Players (Revised History)

SYDNEY GROUP: Minas Coroneo, Jim Morley, Jim Patrick, Gregg Suaning, and later Vivek Chowdhury.

PRINCE OF WALES GROUP (POW): Minas Coroneo and Vivek Chowdhury.

UNIVERSITY OF NEW SOUTH WALES GROUP (UNSW): Gregg Suaning & Nigel Lovell.

BIONIC VISION AUSTRALIA (BVA): Anthony Burkitt (director), David Penington (chairman until 2013), Mark Hargreaves (chairman).

MONASH VISION GROUP (MVG): Anthony Lowery (director), Jim Patrick (advisory board), David de Kretser (chairman).

AUSTRALIAN GROUPS

1997

Suaning begins doctorate on bionic eye University of New South Wales (UNSW). Sydney Group forms.

1998

Sydney group publishes first paper, a review of the field.

2002

Sydney Group splits into Prince of Wales (POW) group and UNSW group due to technical, interpersonal, and intellectual property conflicts.

2003

May
Cochlear Ltd. agrees to provide POW group with equipment for development of a visual cortex implant.

POW group begins animal experiment with visual cortex implant.

2004

POW group reports first animal experiment with visual cortex implant.

2005

POW group & Morley file US patent on extraocular (on sclera) implant. Granted 2011.

June
POW group reports animal experiment with extraocular implant.

October
POW group reports further animal experiment with visual cortex implant.

2006

UNSW Group & ophthalmologist Yves Kerdraon awarded US patent on retinal implant.

March
POW group conducts stimulation experiment on people with extraocular implant.

2008

UNSW group collaborates with Bionic Ear Institute (renamed Bionics Institute in 2011).

May
POW group ready to take epiretinal implant to pre-clinical trial after proof-of-concept tests with 10 volunteers.

2009

June
POW group approached by Second Sight regarding collaboration. POW declines due to long-running conflict over IP between Second Sight co-founder Al Mann & Cochlear which provided technical assistance to POW.

July
Chowdhury writes to ARC, asking to be removed from POW-led application for bionic eye funding. Consequently, ARC disallows consortium's application. POW group disbands.

Melbourne University (MU) researchers approached by Second Sight regarding joint proposal. Disagreement over intellectual property (IP) halts discussion. MU researcher denies approach made.

July
While finalising its own application, BVA learns informally POW application disallowed.

BVA wins $42 million over four years in bionic eye funding.

BVA researchers being work on 3 bionic eye implants: UNSW-led wide-view suprachoroidal implant; MU-led high-acuity epiretinal implant with diamond substrate; Bionics Institute-led wide-view suprachoroidal implant.

MVG wins $8 million in bionic eye funding over four years.

2010

March
Rudd launches BVA consortium.

BVA establishes Bionic Vision Technologies (BVT) to commercialise its retinal stimulation technology.

April
MVG group launched.

October
MVG establishes Gennaris pty Ltd to commercialise its visual cortex Prosthesis.

2012

May
BVA begins trial of Bionics Institute led wide-view suprachoroidal implant with 3 patients.

2013

BVA awarded $9 million extension of bionic eye funding.

August
BVA Scientific Advisory Board (SAB) teleconference. Recommends halting funding to UNSW arm of BVA and recommends to BVA chair that the project director be changed.

September
Internal disagreements lead to the immediate retirement of BVA chair. SAC chair retires soon thereafter.

Quarterly meeting of BVA board rejects SAB recommendations.

MVG received $1.9 million extension of bionic eye funding.

2014

October
BVA announces completion of laboratory study begin in 2012 of Bionics Institute led wide-view suprachoroidal device with 3 patients.

2015

MVG reports at conference that its visual cortex implant is ready for pre-clinical trials in 2016

BVT meets with iBIONICS (Canadian entrepreneurs) to ready BVA's high-acuity epiretinal prosthesis for human trial.

BVT seeks $10 million for further trials of high-acuity epiretinal prosthesis in conjunction with iBIONICS.

February
UNSW arm of BVA & Sydney Eye Hospital begin animal trial of UNSW-led wide-view suprachoroidal prototype.

2016

BVT anticipates human trial of refined Bionics Institute-led wide-view suprachoroidal implant in 2017.

MVG seeks funds for pre-clinical trial of it's visual cortex prosthesis and anticipates human trails of implant in late 2017

By 2016 the UNSW and POW groups and later the BVA and MVA had applied for or received several patents

**All events are supported by open source and/or interview data, as well as by follow-up e-mail correspondence with participants. Some items note only the year, as I do not have precise dates*

Appendix 8: Bionic Eye Timeline (Revised History)

AUSTRALIAN EVENTS

2007

Melbourne University (MU) engineering department holds meeting with Melbourne-based researchers.

UNSW holds bionic eye round table. Includes UNSW group, MU, Centre for Eye Research Australia (CERA), National ICT Australia (NICTA). POW group not invited.

Mid year
NICTA commissions consultant to write strategy for a consortium proposing to build a bionic eye. Consultant concludes it is not fundable by private sector.

2008

February
Prime Minister Kevin Rudd announces Australia 2020 Summit to be co-chaired by Rudd and MU Vice-Chancellor Glyn Davis.

Director of Bionic Ear Institute uses institute funding to develop early technologies with CERA.

Director of UNSW Innovations lobbies for funding for UNSW group & MU collaborators prior to 2020 Summit.

April
MU academic reviews consultant's bionic eye strategy for NICTA. Academic oversees new bionic eye business plan and hands it to MU Vice-Chancellor. VC discusses plan with Prime Minister.

Consultant for NICTA declines invitation to run what becomes BVA.

19-20 April
Australia 2020 Summit in Canberra. Bionic eye not discussed in Health Working Group, but announced as a key outcome by Health Minister at end of summit.

22 April
Front Page story in The Australian about POW group's bionic eye work.

31 May
Rudd releases final report for the Australia 2020 Summit. It says Bionic Eye research could be commercialised with modest support.

Australian doctoral student at University of Southern California (USC) visits Melbourne and Sydney regarding bionic eye research positions, based on his work with USC bionic eye researchers. Intellectual property conflicts raised as barrier to employment.

22 July
Media release from Science Minister Kim Carr's office announcing medical bionics conference in Victoria, hosted by the Bionic Ear Institute.

16-19 November
Medical Bionics Conference held in Lorne, Victoria, chaired by Director of the Bionic Ear Institute. POW group not invited.

Mid-December
Kevin Rudd asks Chief Scientist Penny Sackett to arrange review of unsolicited submissions for bionic eye funding from POW and Melbourne groups. Review to be completed before year's end.

Review panel concludes POW group is ready to fund, but Melbourne is not. No funding is offered to either group.

2009

Science Minister Kim Carr asks Australian Research Council head, Margaret Sheil, for advice on how to organise funding for bionic eye initiative. Followed-up by Carr's advisers.

As part of the government's response to the Australia 2020 summit, Carr and Health Minister Nicola Roxon announce funding of $50.7 million over four years for the development of an Australian bionic eye, Project Title: Special Research Initiative in Bionic Vision Science and Technology.

Australian USC doctoral student contacts Queensland Trade Commissioner Peter Beattie about possible joint Queensland (Qld), USC and Second Sight proposal. Beattie meets representatives from USC and Second Sight in California.

June
Australian USC doctoral student's supervisor sends him to meet Queensland researchers, politicians, and university and government officials about joint Queensland, Second Sight & USC application. Mixed interest from University of Queensland (UQ). Queensland University of Technology (QUT) enthusiastic.

Peter Beattie encourages Queensland researchers, Second Sight and USC to submit joint application.

July 29
Applications for ARC bionic eye funding closed. Seven consortia apply, including two from Melbourne, one of which includes UNSW group, and a Queensland-US consortium. (ARC declines to identify applicants.)

15 December
Australian Research Council announces three applications short-listed with funding of $42 million awarded to BVA and $8 million to MVG. Funding to run 2010-2013. (ARC declines to identify third & unsuccessful short-listed applicant.)

2012

June
MVG and BVA chairs meet to identify government funding for 3 years beyond 2014 to complete development and clinical trials of 1 MVG and 2 BVA devices.

2013

12-14 February
ARC panel reviews MVG and BVA. Draft results released to groups in April. Not released publicly.

9 July
Carr announces 1-year extension to bionic eye funding: $8 million to BVA & $1.9 million to MVG.

INTERNATIONAL ADVANCES

2002

US firm Second Sight Medical Products Inc begins clinical trial of Argus I Retinal Prosthesis with 6 subjects.

2005

German firm Retina Implant AG begins pilot study with 11 volunteers.

2006

Second Sight Medical Products Inc begins pilot study of Argus II Retinal Prosthesis with 2 patients, followed by a 30-patient trial in 10 centers across Europe and the US.

2009

Retina Implant AG begins clinical trial with 20 patients.

2011

May
Second Sight Medical Products Inc. receives European approval (CE) to market its Argus II Retinal Prosthesis in the European Union & European Free Trade Association.

2013

14 February
Second Sight Medical Products Inc. receives US Food & Drug Administration approval to market the Argus II Retinal Prosthesis in US.

6 November
Retina Implant AG receives CE approval to market its Alpha IMS retinal prosthesis in the European Union & European Free Trade Association.

2015

1 July
Second Sight's Argus II Prosthesis "turned on" for first time for patient with age-related macular degeneration. Previously only used for patients with retinitis pigmentosa.

2016

French Firm Pixium Vision begins multi-centre clinical trial of IIRIS II epiretinal implant.

Pixium Vision obtains CE Mark in Europe to market IRIS II implant.

**Some items note only the year, as I do not have precise dates*