Australia's National
Science Agency

Value of science and technology

Opportunities for Australia to overcome innovation challenges and realise greater value from innovation investments

November 2020

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Stakeholders consulted

We thank the following stakeholders who provided their valuable insights during the development of the *Value of science and technology* report:

Dan Bailey
Impact Monitoring and Evaluation Specialist, Performance & Evaluation, CSIRO

Antonio Balaguer
Assistant Manager, Analysis and Insights Division, Department of Industry, Science, Energy and Resources

Professor Hugh Bradlow
President, Australian Academy of Technology and Engineering

Dr Kate Cameron
A/g Chief Executive Officer, Office of Industry Innovation and Science Australia

Mary Cavar
Executive Manager (Melbourne), Productivity Commission

Rowan Conway
Head of Mission Oriented Innovation Network, UCL Institute for Innovation and Public Purpose

Dr Anne-Maree Dowd
Executive Manager, Performance & Evaluation, CSIRO

Luci Ellis
Assistant Governor (Economic), Reserve Bank of Australia

Dr Cathy Foley
Chief Scientist, CSIRO

Professor Joshua Gans
Jeffrey Skoll Chair in Technical Innovation and Entrepreneurship, University of Toronto

Professor Martin Green
Director, Australian Centre for Advanced Photovoltaics, University of New South Wales

Emeritus Professor Roy Green
Deputy Vice-Chancellor (Innovation & Enterprise), Special Advisor and Chair UTS Innovation Council, University of Technology Sydney

Sarah Hunter
Chief Economist, Oxford Economics

Professor Paul Jensen
Deputy Dean, Faculty of Business and Economics, University of Melbourne

Mark Johnson
A/g General Manager, Strategic Policy Division, Department of Industry, Science, Energy and Resources

Dr Thomas Keenan
Director, Tractuum

Dr Danielle Logue
Associate Professor of Innovation, Entrepreneurship & Strategy, University of Technology Sydney

Sue-Ellen Luke
Director of Technology, Innovation and Business Characteristics, Australian Bureau of Statistics

Dr Benjamin Mitra-Kahn
General Manager and Chief Economist, IP Australia

Phil Morle
Partner, Main Sequence Ventures

Victoria Savage
Assistant Director, Australian Bureau of Statistics

Dr Jack Steele
Director, Science Impact and Policy

Dr Abrie Swanepoel
A/g General Manager, Analysis and Insights Division, Department of Industry, Science, Energy and Resources

Razib Tuhin
Manager, Analysis and Insights Division, Department of Industry, Science, Energy and Resources

Professor Beth Webster
Director of the Centre for Transformative Innovation, Swinburne University

Professor Hugh Williams
Melbourne Business School and The University of Melbourne

Innes Willox
Chief Executive, Australian Industry Group

Dr Marcus Zipper
Director, CSIRO Manufacturing

Executive summary

Science and technology have always played a key role in supporting Australia's growth and productivity. However, with a weak economy and COVID-19, science and technology are now more critical than ever.

While Australia's economic track record has been impressive, recent years have seen slowing economic growth and productivity, and low economic complexity. Australia has also witnessed significant structural shifts both nationally and internationally, and now COVID-19 has introduced additional challenges. Science and technology (S&T) innovation is part of the solution, helping businesses and industries deliver strategic goals and solve society's greatest challenges.

Science and technology innovation helps improve productivity, can provide social and environmental benefits, builds resilience, and enhances international competitiveness.

The CSIRO *Australian National Outlook 2019* report showed Australia is at a crossroads, with one path towards a slow decline and another towards a more positive future of strong and inclusive growth. By engaging in solution-focused collaboration, and committing to continuous improvement, Australia can build an innovation-led future. Australia has shown what it can achieve, through decades-long investment in pandemic research and planning, and its massive and rapid response to COVID-19. This recent experience provides the motivation needed to tackle other looming national challenges in a similar innovation-led way.

While Australia is strong in research, it has not been as successful in translating this into valuable economic outputs. The *Value of science and technology* report examines the mechanisms through which S&T innovation creates value and can drive economic recovery and future resilience. The study aims to demonstrate that investing in S&T innovation can have substantial benefits and identifies the key areas for change for Australia to realise the value from S&T investment. The research underpinning the report includes an extensive review of the vast literature that already exists on this topic and consultation with 35 private and public sector leaders. This report endeavours not to replicate the effort of others, but to acknowledge this previous work, and to focus on opportunities that are particularly relevant to the research-industry nexus, and to an innovation-led path to post-COVID-19 economic recovery and future resilience.

Businesses can realise greater value from innovation by driving purposeful and solutions-focused innovation, sectoral and international collaboration, and fostering a 'growth through innovation' culture.

This report identifies several innovation challenges facing businesses and discusses the economic implications of the challenges. The report also demonstrates that there are plenty of opportunities for businesses to enhance how they navigate the innovation cycle and realise greater value from their investments.

This report is part of a series examining the importance of science and technology in driving economic growth. The *COVID-19 Recovery and resilience* report outlines growth opportunities for Australian businesses and is available from www.csiro.au/futures.

Table 1: Challenges and opportunities at the research-industry nexus

	CHALLENGES	OPPORTUNITIES
Business investment	• Declining investment in R&D innovation, particularly by business • Investment not being targeted to long term strategic goals or addressing future challenges	• Industry-research collaboration for purposeful, impactful and strategically balanced investment • Refocusing investment in sectors with clear competitive and comparative advantages
Commercialising R&D	• High-quality research, but under-commercialisation and novelty • Lack of collaboration across industries, between research and industry, and internationally • Cultural aversion to risk	• Promoting solutions-focused research for commercial and broader applications • Promoting industry-research links and collaboration over competition • Promoting a 'growth through innovation' culture
Skills, Knowledge and Capabilities	• Skills mismatches and shortages in areas relevant to innovation • Low ability of businesses to absorb knowledge to adopt and adapt new ideas (absorptive capacity)	• Supporting upskilling, interdisciplinary programs, and work-based continuous learning • Supporting innovation management skills and information sharing
Adoption and Diffusion	• Few Australian businesses looking beyond the domestic market for innovations to adopt • Restricted spread of innovation across Australia	• Adopting more from overseas and across industries and diffusing via incremental improvements • Drawing on non-R&D innovation, such as digital transformation and business model innovation • Developing innovation clusters and expanding growth industries
Social and Environmental Impacts	• Maximizing the benefits and mitigating the costs of innovation for society and the environment	• Preparing workforces for change • Coordinated, socially engaged and sustainable innovation

1 Introduction

1.1 This report

1.1.1 Objective

The *Value of science and technology* report brings CSIRO's economic capability to examine the case for investing in science and technology (S&T) innovation. The study aims to demonstrate that investing in S&T innovation can have substantial benefits and identifies the key areas for change for Australia to realise the value from the investment.

1.1.2 Approach

The report is underpinned by extensive desktop research of the vast existing literature on this topic and consultations with approximately 35 government, business and research leaders to test and expand on the research findings, particularly around the challenges, opportunities and enabling actions required.

While there are many lenses to view innovation and the valuable impact created from it, this report is led by CSIRO economists and focused primarily on:

- The economic impact of S&T innovation (the report uses the terms S&T innovation and research and development (R&D) innovation[1] interchangeably to describe new or improved products or processes[2] created through S&T). Although the focus is mainly on R&D innovation, 'non-R&D' innovation and innovation (the combination of R&D and non-R&D innovation) are also discussed given all forms of innovation are vital for the efficacy of the innovation ecosystem[3]
- The research-industry nexus and opportunities for businesses to realise more value from S&T
- Examples demonstrating quantified value in economic or financial terms. However, the report also draws on qualitative examples where Australia has achieved impact in social, environmental and health terms (with the aim to quantify these broader impacts in future studies).

Several studies have introduced an innovation cycle, a guide illustrating the process of innovation from idea to impact.[4] This study has also developed an innovation cycle, to describe and assess the pathways through which innovation creates value for the business and impact to the economy (see Figure 1). This innovation cycle was used to structure the analysis. As there are various drivers of innovation, innovation types and pathways to impact, it is difficult to summarise these in a single diagram. However, the innovation cycle illustrates the possible steps along which innovation occurs at a high level. It should be noted that each step can affect other stages of the cycle in a virtuous, non-linear way, and organisations may enter later in the cycle and still successfully navigate from an idea to impact (see also Appendix B for more details on the innovation cycle steps).

1 R&D and 'non-R&D' innovation as according to ISA. (2020). *Stimulating Business Investment in Innovation*. https://www.industry.gov.au/sites/default/files/2020-02/stimulating-business-investment-in-innovation.pdf

2 Product and process innovation as according to OECD. (2018). Chapter 3: Concepts and definitions for measuring business innovation. *Oslo Manual 2018: Guidelines for Collecting*. (pp. 67-83). Reporting and Using Data on Innovation, 4th edition

3 Non-R&D refers to the difference between difference between broader innovation measures and R&D. Examples of non-R&D include IP protections; planning, designing, testing and acquiring assets for the purposes of innovation; business model adaptation; marketing and so on. According to AlphaBeta (2020) non-R&D innovation is more widespread than R&D innovation in Australia, and it may also be a stronger driver of productivity than R&D.

4 See for example: DIIS, Office of the Chief Economist. (2016). *Australian Innovation System Report 2016.* https://www.industry.gov.au/data-and-publications/australian-innovation-system-report/australian-innovation-system-report-2016

1.1.3 Report structure

The rest of Chapter 1 summarises Australia's economic context, why innovation is now more important than ever, and how businesses can benefit from driving innovation. Chapter 2 examines the challenges businesses face in realising value from innovation investment and identifies opportunities to overcome each of these. Finally, the report concludes that action is required to achieve medium-term economic recovery and long-term resilience, and comments on further steps that may be taken to measure progress and impact.

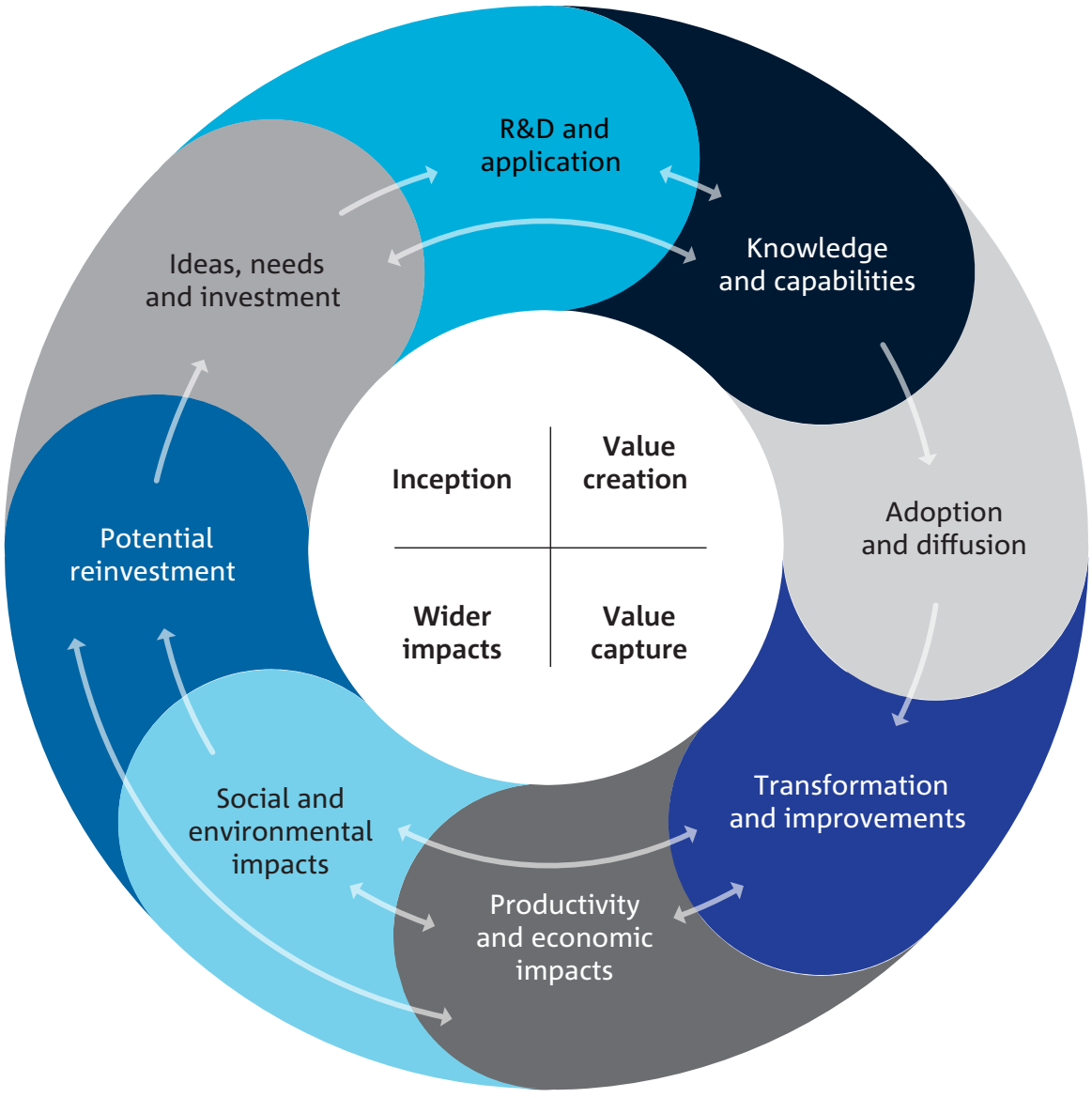


Figure 1: The Innovation Cycle

1.2 The Australian context

Even before COVID-19, the Australian economy was showing signs of weakness and causes for concern.

Australia enjoyed nearly three decades of uninterrupted economic growth starting in 1991, with increased median wealth, relatively strong employment opportunities, and a high level of social cohesion. However, as discussed in the CSIRO *Australian National Outlook 2019* report, in the few years prior to the COVID-19 outbreak, the Australian economy was showing signs of weakness and causes for concern, including low economic growth, low productivity growth and low business investment in R&D. Figure 2 illustrates this downward trend with changes in gross domestic product (GDP), multi-factor productivity (MFP) and business expenditure in R&D (BERD) over the last 15 years. At the business level, continued uncertainty disincentivised investment. At the household level, low wage growth and high household debt left Australians vulnerable to shocks. At the economy level, Australia's reliance on migration-driven labour productivity, low economic and export complexity (and low diversity) left the economy also vulnerable to shocks.

Refocusing attention on S&T innovation can address Australia's stagnating productivity and slowing economic growth.

S&T innovation can be part of the solution to solving Australia's significant economic, social and environmental challenges.[5] There are many benefits of S&T innovation to businesses and Australia (see section 1.2), and despite the challenges preventing businesses from realising value from innovation investment, there are plenty of opportunities to overcome these challenges (see Chapter 2).

Productivity and economic growth are needed to improve the economic wellbeing of Australians, with productivity historically being the predominant source of income growth.[6] Productivity is the ability to produce a larger share of higher-quality economic outputs with the same or fewer inputs. Productivity saves valuable resources, boosts business profits and increases the ability of the economy to respond to change.[7]

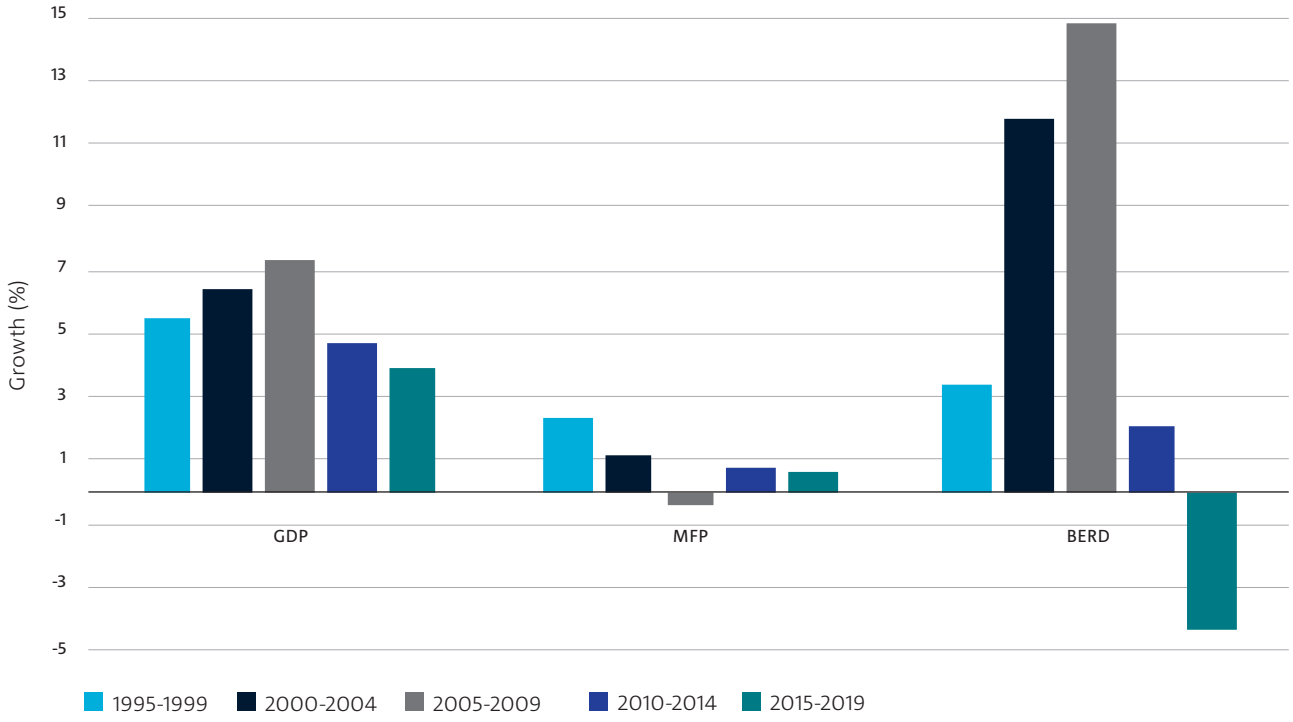


Figure 2: Change in GDP, Productivity, and Business Expenditure on R&D since 1995

Sources: ABS (2019) Estimates of Industry Multifactor Productivity Australia; ABS (2018) Research and Experimental Development, Businesses, Australia; ABS (2019). Australian National Accounts: National Income, Expenditure and Product Table 1. Key National Accounts Aggregates

5 Industry Innovation and Science Australia (2017). *Australia 2030*; CSIRO. (2019). *Australian National Outlook*.

6 Australian Government Treasury. (2012). *The importance of productivity.* https://treasury.gov.au/speech/the-importance-of-productivity

7 Productivity Commission. (2017). *Productivity and Income — The Australian Story, Shifting the Dial: 5-year Productivity Review, Supporting Paper No. 1*. https://www.pc.gov.au/inquiries/completed/productivity-review/report/productivity-review-supporting1.pdf

Productivity in Australia has been slowing, driven by declining innovation-driven technological progress (captured by MFP) and by declining labour productivity and migration.[8] Figure 3 illustrates a downward trend in both MFP and labour productivity since 1995. Although slowing productivity is common to advanced economies in recent years (for a more detailed discussion see Appendix E: The Productivity Paradox),[9] a combination of Australia's heavy reliance on labour productivity and low economic complexity (discussed on page 9) is concerning and leaves Australia particularly vulnerable to shocks. As the influence of labour productivity diminishes, Australia's economic growth will increasingly rely on technological progress, and so addressing the challenges throughout the innovation cycle is more important than ever.

Economic growth is driven by productivity, population and participation. The role played by innovation-driven productivity, is increasingly important for economic growth. While much of Australia's economic growth has historically been attributable to labour (particularly migration-driven population increases),[10] as wage growth stagnates, the contribution of labour growth to overall economic growth also diminishes. Economic growth has been slowing in Australia over the past seven years, with GDP growing only 2% in 2018-19, the lowest rate in a decade.[11] GDP per hour worked, fell from a decadal average of 13% between 2000 to 2010 to 10% from 2008 to 2018.[12] Looking forward, the recent economic shocks due to COVID-19 and the bushfires have added considerable uncertainty to Australia's economic outlook. COVID-19 related slowing demand for exports from Asian economies will likely compound the economic slowdown in Australia.[13] However, Australia's economy has remained resilient to global recessions in the past (notably the global financial crisis). Close trade relationships with Asian nations (especially China) and relatively inelastic commodity exports have bolstered Australia's economy.[14] Although the nature of the recovery is unclear at present, boosting productivity and economic growth will remain challenges of primary importance.

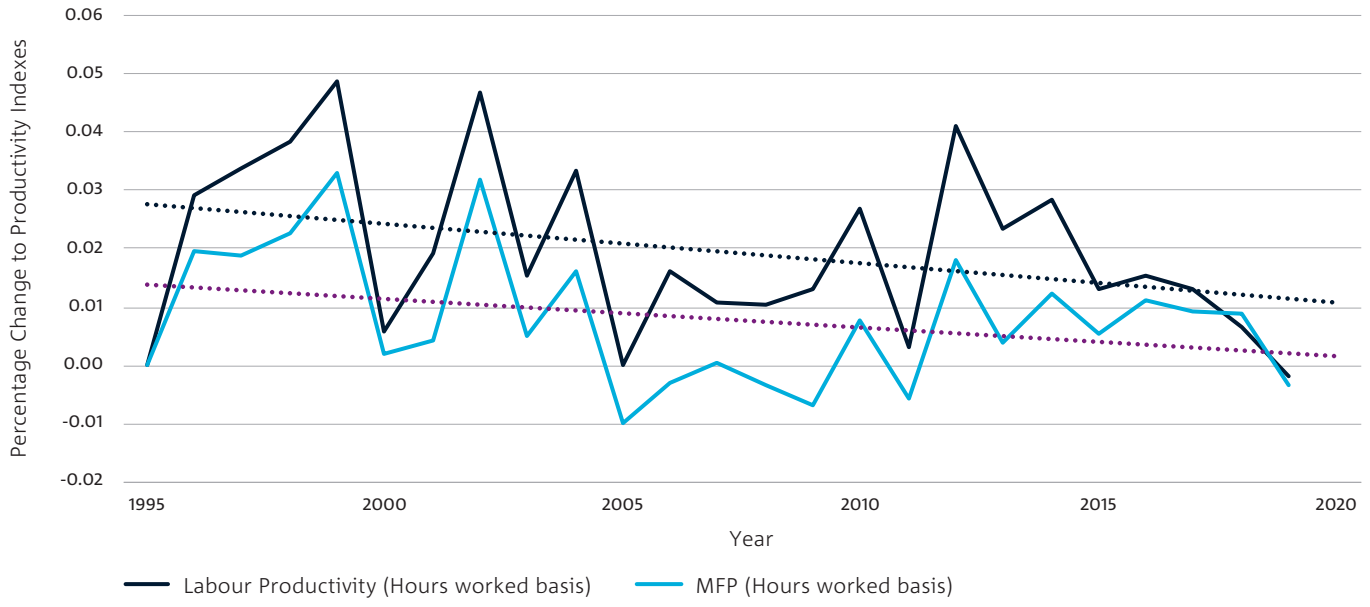


Figure 3: Australian Multifactor and Labour Productivity Growth

Data Source: ABS (2019) Estimates of Industry Multifactor Productivity Australia

8 MFP, a component of overall productivity which captures technological progress, has been declining from a decadal growth rate of 1.4% from 1994-95 to 2004-05 to an average of 0.4% from 2004-05 to 2018-19: Productivity Commission. (2020). *Productivity Insights February 2020*. https://www.pc.gov.au/research/ongoing/productivity-insights/recent-productivity-trends/productivity-insights-2020-productivity-trends.pdf. Although Australia's overall productivity has historically relied most heavily on the productivity of labour, this has also slowed, partially driven by lower MFP growth: OECD (2015). *The Future of Productivity*. Joint Economics Department and the Directorate for Science, Technology and Innovation Policy Note. http://www.oecd.org/economy/growth/The-future-of-productivity-policy-note-July-2015.pdf; Campbell, S., & Withers, H. (2017). *Australian Productivity Trends and the Effect of Structural Change, Economic Round-up*. https://treasury.gov.au/publication/p2017-t213722c. In 2018-19, economy-wide labour productivity declined by 0.2%, below the five-year average of 0.9% growth; and far below the long-run growth rate of 2% since the 1970s: Australian Bureau of Statistics. (2018). Australian System of National Accounts, 2017-18, Cat. no. 5204.0, tables 1, 5, 15, 46 and 58; Australian Bureau of Statistics (2018). Labour Force, Australia, Detailed, Quarterly, Cat. no. 6291.0.55.003, Aug 2018, Table 11.

9 Gordon, R., & Dew-Becker, I. (2005). Where Did the Productivity Growth Go? Inflation Dynamics and the Distribution of Income. *NBER Working Paper, 11842*. Brookings Papers on Economic Activity. https://www.nber.org/papers/w11842

10 OECD (2019). *OECD Compendium of Productivity Indicators 2019*. https://www.oecd-ilibrary.org/industry-and-services/oecd-compendium-of-productivity-indicators-2019_b2774f97-en

11 Australian Bureau of Statistics. (2020). *Australian National Accounts: National Income, Expenditure and Product*, December 2019, Cat. no. 5206.0. ihttps://www.abs.gov.au/statistics/economy/national-accounts/australian-national-accounts-national-income-expenditure-and-product/dec-2019

12 OECD. (2019). Productivity Statistics: GDP per capita and productivity growth. https://www.oecd.org/sdd/productivity-stats/

13 Oxford Economics. (2020). *The Economic Impact of COVID-19 on Asia Pacific*. https://www.oxfordeconomics.com/recent-releases/The-Economic-Impact-of-COVID-19-on-Asia-Pacific

14 Australian Treasury. (2012). *The Australian economy and the global downturn Part 1: Reasons for resilience*. https://treasury.gov.au/publication/economic-roundup-issue-2-2011/economic-roundup-issue-2-2011/the-australian-economy-and-the-global-downturn-part-1-reasons-for-resilience

Australia's low **economic complexity** is a third economic weakness that compounds stagnating productivity and economic growth.[15] Australia's exports are highly concentrated in a few industries, as captured by Harvard University's Economic Complexity Index, which compares the diversity, uniqueness and knowledge intensity of a country's export profile relative to global peers.[16] As seen in Figure 4, Australia is an outlier in its low economic complexity relative to per capita income, and the only advanced economy with low economic complexity.[17] It ranked 87th (of 133 countries) globally, down from a previous rank of 57th in 1997.[18] This is further reflected in the knowledge and technology intensity of many of its exports, noting that Australia ranks 62nd in the world for high-tech exports, and 82nd for ICT service exports as a percentage of total trade.[19] Studies show that countries with higher economic complexity tend to generate higher per capita income and are more resilient to global economic downturns.[20] While Australia has a history of generating its economic growth from a small number of commodity exports, its low and relative decline in economic complexity may also reflect unrealised potential to leverage its comparative and competitive advantages, develop new exportable products and industries, and build future resilience.

Now COVID-19 has introduced additional challenges and opportunities.

COVID-19 has brought about a significant global shock, and the world has witnessed significant health, economic, and social impacts. This has also exacerbated many of the economic, environmental and social challenges that were present before COVID.

With millions of confirmed cases and hundreds of thousands of confirmed deaths, the world has experienced a significant health shock. Australian S&T innovation has focused on disease preparedness for decades, placing Australia in an excellent position to respond rapidly to COVID-19. COVID-19 has spurred increases in R&D investment and activity, particularly in medical and biological research sectors, as businesses work on a vaccine. But unless and until a vaccine is available, COVID-19 will continue to have substantial health impacts.

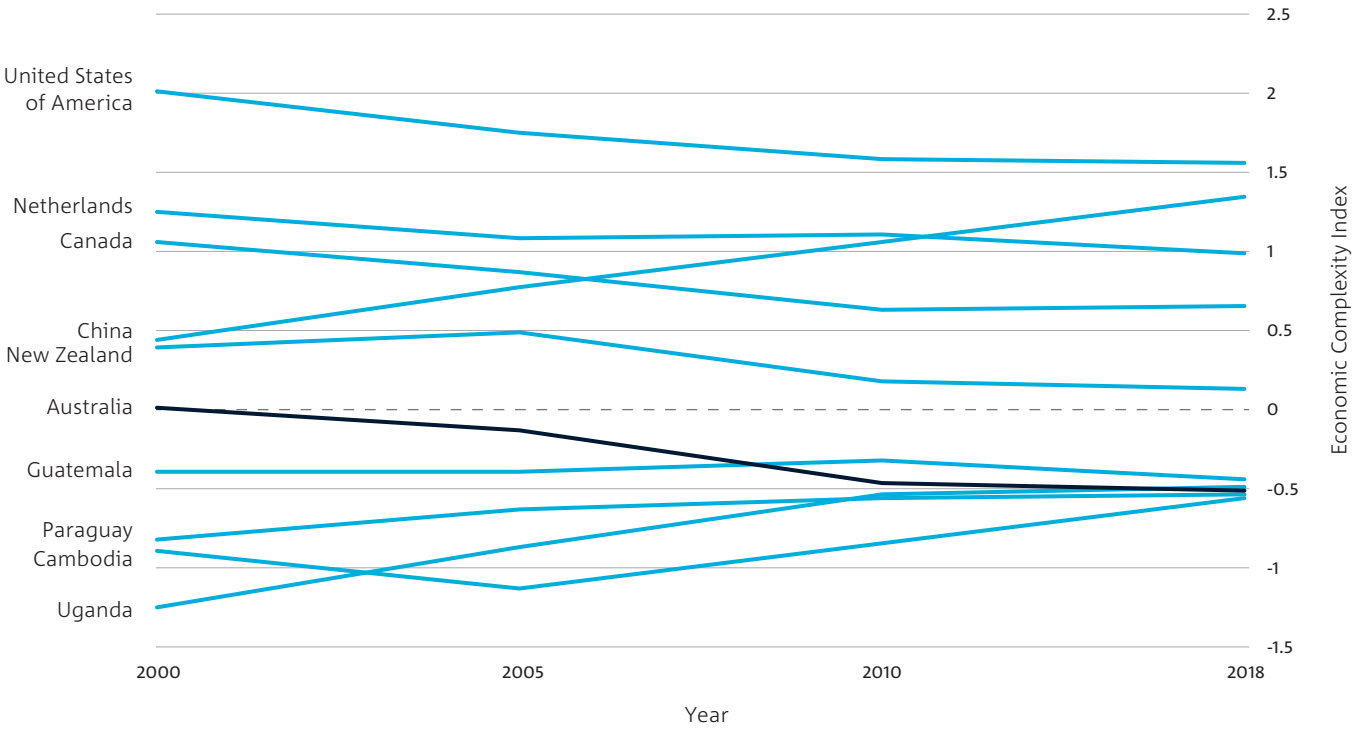


Figure 4: Economic Complexity Index, OECD Countries 2018

Data Source: Harvard University (2020). Atlas of Economic Complexity

15 Economic complexity refers to the composition of a country's productive output. Increased economic complexity is associated with creating and disseminating productive knowledge, and it reflects the structures needed to support such knowledge.

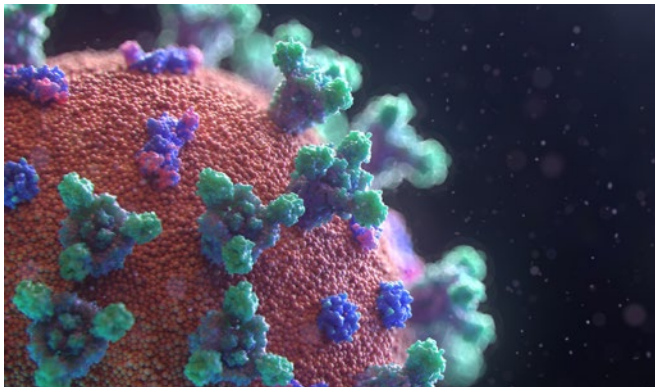
16 Harvard University. (2019). *The Atlas of Economic Complexity*. https://atlas.cid.harvard.edu/rankings

17 Office of the Chief Economist (2018). *3/2018 Future Productivity*. https://publications.industry.gov.au/publications/industryinsightsjune2018/future-productivity.html

18 Harvard University. (2019). *The Atlas of Economic Complexity*. https://atlas.cid.harvard.edu/rankings

19 Global Innovation Index. (2020). *Australia – Economy analysis*. https://www.globalinnovationindex.org/analysis-economy

20 Office of the Chief Economist. (2018) *2/2018 Globalising Australia*. https://publications.industry.gov.au/publications/industryinsightsjune2018/documents/IndustryInsights_2_2018_ONLINE.pdf



Border controls have prevented international business travel, tourism and education, and domestic restrictions on movement have limited many sectors but especially hospitality, retail, the arts and recreation, and local tourism. The combination of social distancing, lower incomes for many and increased uncertainty are reducing aggregate demand and cash flow for both businesses and governments. Governments around the world, including Australia, have provided economic stimulus packages. Australia's staged stimulus packages include support for households, businesses, employment, and the financial system, and they represent the largest and fastest economic support in the country's history. The 2020-21 Federal Budget and Economic Recovery Plan delivered on 6 October 2020 outlines several measures designed to support an innovation-led path to economic recovery and growth.[21] These include additional investment into the Research and Development Tax Incentive, as well as funding for the Modern Manufacturing Strategy, which focuses on building competitiveness, scale and resilience across the manufacturing sector in six National Manufacturing Priorities.[22] The Budget also provides support for low emissions technologies, network infrastructure, dispatchable generation and reliable renewable energy supplies.[23] These measures set the stage for more medium- and long-term measures in future budgets, enabling Australia to tackle other challenges through innovation.

Socially, Australia has witnessed significant changes with regards to workplace flexibility, and how to manage this with caregiving, and other family and social obligations.[24] Australia has similarly witnessed significant changes with regards to socialising and consumption. At the business level, consumer and business digital adoption has made five years of progress in just eight weeks,[25] and 38% of Australian business changed their delivery method and moved their business online.[26]

The CSIRO *Australian National Outlook 2019* report shows what Australia's future might look like, depending on how it responds to these challenges. On the one hand, without strong actions to address the challenges, Australia risks falling into a slow decline. Alternatively, through purposeful, coordinated action, supported by innovation, Australia can address the challenges and achieve strong and inclusive growth, energy transition and emissions reduction, and greater social cohesion and equality.

Building on the *Australian National Outlook 2019*, as well as CSIRO's industry roadmaps,[27] the CSIRO *COVID-19: Recovery and resilience* report identifies science and technology growth opportunities that can help restore economic growth in response to the pandemic.[28] The report highlights how businesses can realise significant economic value from science and technology over the next 6-24 months and identifies longer-term opportunities for Australia to build a resilient and future-proof economy from 2022 and beyond.

Affirming a collaborative, solution-focused and innovation-led vision for Australia, CSIRO has announced a program of missions aimed at meeting the nation's challenges and supporting a future economy augmented and accelerated by science and technology.[29] CSIRO will commit at least $100 million annually to this program and work closely with government, universities, industry and the community to co-create and deliver the missions.[30] The missions are intended to secure Australia's wellbeing and prosperity for generations to come and address Australia's greatest challenges, including health and wellbeing, sustainable energy and resources, and future industries.

Decades-long investment in R&D and pandemic planning and the current response to COVID-19 demonstrate what Australia can achieve and provides and motivation to tackle other looming challenges in a similarly innovation-led way.

21 Australian Government. (2020). *Budget 2020-21*. https://budget.gov.au/

22 Australian Government. (2020). *Modern Manufacturing Initiative and National Manufacturing Priorities announced*. https://www.industry.gov.au/news-media/modern-manufacturing-initiative-and-national-manufacturing-priorities-announced. The National Manufacturing Priorities are: Resources Technology & Critical Minerals Processing; Food & Beverage; Medical Products; Recycling & Clean Energy; Defence; and Space.

23 Australian Government. (2020). *Budget 2020-21*. https://budget.gov.au/

24 See for example current University of Queensland research into the impact of COVID-19 on society, available at https://issr.uq.edu.au/article/2020/05/issr-research-impact-covid-19-society-and-actions-take-reduce-and-recover-impact,%20last%20accessed%2018%20May%202020.

25 Baig, A., Hall, B., Jenkins, P., Lamarre, E. & McCarthy, B. (2020) *The COVID-19 recovery will be digital: A plan for the first 90 days*. McKinsey Digital. www.mckinsey.com/business-functions/mckinsey-digital/our-insights/the-COVID-19-recovery-will-be-digital-a-plan-for-the-first-90-days?cid=other-eml-alt-mbl-mck&hlkid=ffa7f7dace64429f82c354ddf40accb6&hctky=11986719&hdpid=dfb4c609-2604-4df3-aa42-ae7ed2aff045

26 Australian Bureau of Statistics. (2020). 5676.0.55.003 *Business Indicators, Business Impacts of COVID-19.* [Latest Release]. www.abs.gov.au/AUSSTATS/abs@.nsf/Previousproducts/5676.0.55.003Main%20Features4Week%20Commencing%2030%20March%202020?opendocument&tabname=Summary&prodno=5676.0.55.003&issue=Week%20Commencing%2030%20March%202020&num=&view

27 CSIRO. (2020). *CSIRO Futures reports*. https://www.csiro.au/en/Do-business/Futures/Reports

28 CSIRO. (2020). *COVID-19: Recovery and resilience*. https://www.csiro.au/en/Do-business/Futures/Reports/Innovation-and-business-growth/COVID-19-recovery-resilience

29 CSIRO. (2020). *Mission possible – A vision for Australia's recovery and future resilience*. https://www.csiro.au/en/News/News-releases/2020/Speech-to-the-National-Press-Club; CSIRO (2020). *Partner with us to tackle Australia's big challenges*. https://www.csiro.au/en/Showcase/Challenges-missions

30 CSIRO. (2020). *Mission possible – A vision for Australia's recovery and future resilience*. https://www.csiro.au/en/News/News-releases/2020/Speech-to-the-National-Press-Club

1.3 Benefits of science and technology innovation for businesses

Science and technology have created valuable impact for Australian businesses and continue to do so today.

Businesses have a vital role in driving S&T innovation and can realise significant value from doing so. Through innovation, businesses can create new products and services, increase the quality of existing goods and services, and be more productive and profitable. Innovation can also enable businesses to become more competitive internationally. Innovation aimed towards achieving social and environmental objectives can help businesses maintain a social licence to operate. Innovation can also help businesses manage their internal and external risks better and generate spillover effects within industrial clusters.

1.3.1 Creating new products, services and industries

Innovation creates new products and services,[31] and creates new (or extends existing) industries and markets, with positive flow-on impacts for revenue and jobs in the economy. There are several examples of Australian innovations that either created new industries or were pivotal to extending existing industries. These include the electronic pacemaker, Aerogard, ultrasound scanner, cochlear implant, PERC solar cells and Wi-fi (see Appendix D for more examples). Examples of future industries that could be unlocked by S&T in Australia include the quantum technology industry, the hydrogen industry, and the space industry.[32] Technologies can also combine to form new product and service offerings, opening up new markets.[33] For example, emerging technologies such as AI, AR, blockchain, robotics, IoT, drones, 3D printing and VR, are integrated into single applications that change the way Australians work and live.[34]

Cochlear implants[35]

Motivation: To provide a solution for hearing loss.

Type of innovation: Product.

Commercialisation path: R&D in Australia, Australian and Chinese manufacturing operations.

Impact: 600,000 implants worldwide (250,000 from Australian-derived technology) with significant quality of life improvements, annual revenue of $1.24 billion, global workforce of 3,500.

The cochlear implant, also known as the bionic ear, was invented by Australian Dr Graeme Clark to provide a solution for hearing loss. The cochlear implant is a medical device implanted into the cochlea, which provides an altered sense of sound to those with hearing loss. The invention was developed through a long trajectory of basic research in public universities and hospitals, and commercialised through joint industry, research and government efforts, including public funding, with manufacturing operations in Australia and China. Cochlear Limited, an Australian company formed to commercialise the multi-channel implant, holds two-thirds of the hearing implant market globally, has a market capitalisation of over $12 billion and had annual revenue of $1.24 billion in 2017. Since the formation of Cochlear Limited in 1982, over 250,000 people have received their implants. The implants have greatly improved the quality of life of many individuals, and approximately 600,000 individuals have received cochlear implants worldwide, Dr Clark's model being the most widely used system.

31 OECD. (2019). *Oslo Manual 2018: Guidelines for collecting, reporting and using data on innovation. 4*th *Edition*. https://www.oecd.org/science/oslo-manual-2018-9789264304604-en.htm; ISA. (2020). *Stimulating business investment in innovation*. https://www.industry.gov.au/sites/default/files/2020-02/stimulating-business-investment-in-innovation.pdf

32 See CSIRO Futures' industry reports: https://www.csiro.au/en/Do-business/Futures/Reports

33 Park, H. (2017). Technology convergence, open innovation and dynamic economy. *Journal of Open Innovation: Technology, Market and Complexity*. 3(24)

34 PwC. (2020). Infographic: Six emerging tech trends changing our world. *Digital Pulse*. https://www.digitalpulse.pwc.com.au/infographic-six-emerging-technology-trends/

35 References for this case study: Brocklehurst, E. (2013). *Questions Mount Over Cochlear's Top Status*. FN Arena. https://www.fnarena.com/index.php/2013/02/06/questions-mount-over-cochlears-top-status/; Clark, G.M. (2008). Personal reflections on the multichannel cochlear implant and a view of the future. *Journal of Rehabilitation Research and Development*, 45(5), 651-694. https://doi.org/10.1682/jrrd.2007.05.0064; Cochlear Limited. (2015). *2015 Cochlear Limited Annual Report*. https://www.cochlear.com/intl/about/investor/annual-reports; Cochlear Limited. (2017). *2017 Cochlear Limited Annual Report*. https://www.cochlear.com/intl/about/investor/annual-reports; Redrup, R. (2019). Cochlear profits jump 13%, despite slow implant sales. *Australian Financial Review*. https://www.afr.com/companies/healthcare-and-fitness/cochlear-profits-jump-13-per-cent-despite-slow-implant-sales-20190813-p52gox; O'Neill, C., O'Donoghue, G.M., Archbold, S.M., Normand, C. (2009). A Cost-Utility Analysis of Pediatric Cochlear Implantation. *Largyngoscope*, 110(1), 156-60 doi:10.1097/00005537-200001000-00028; Powerhouse Museum. (2012). *History: Who developed the cochlear implant and why?* https://web.archive.org/web/20121018061818/http://www.powerhousemuseum.com/hsc/cochlear/history.htm; Tasmanian Government Department of Health – Tasmanian Health Service. (n.d.) *What is a Cochlear Implant and how does it work?* https://www.dhhs.tas.gov.au/service_information/services_files/RHH/treatments_and_services/statewide_audiology_service/cochlear_implant/what_is_a_Cochlear_Implant_and_how_does_it_work; The Ear Foundation. (n.d.) Cochlear Implant Information Sheet. https://www.earfoundation.org.uk/hearing-technologies/cochlear-implants/cochlear-implant-information-sheet

1.3.2 Increasing business and economy-wide productivity, performance and profit

S&T innovation enables individuals, businesses, industries and economies to increase productivity and performance. At the individual level, innovation, particularly automation, digitisation and computing, allows workers to spend more time on more productive human-oriented tasks that require social, emotional and higher cognitive skills (as opposed to physical, manual and basic cognitive skills).[36] At the business level, innovating Australian businesses are twice more likely to report increased productivity than non-innovating businesses,[37] including Australian small- and medium-enterprises (SME).[38] The share of businesses that innovate, including inventing and adopting, is a stronger predictor of productivity growth than investment in innovation.[39] 89% of Australian businesses that innovate experience benefits from innovation, with 42% finding that innovation improves their customer services.[40] Globally, frontier businesses, defined as businesses within an industry with the highest rates of productivity growth, experience greater sales and profitability relative to their industry peers.[41] In Australia, innovating businesses are 40% more likely to experience income and profitability growth than non-innovating businesses.[42]

Economy-wide, S&T innovation contributes to economic productivity and growth. For over 70 years, economists have recognised that S&T innovation plays an important role in driving long run economic growth. Solow analysed empirical data back in 1956 and found technological change is the dominant driver of long run economic growth.[43] More recent studies, with robust empirical evidence, have confirmed S&T innovation leads to long run increases in productivity and economic growth at the business, state and national levels.[44] Innovation accounts for the majority of Australia's overall productivity as measured by MFP,[45] with recent studies estimating that at least 60% of productivity comes from innovation.[46] Meanwhile, about 14% of the Australian economy is estimated to rely directly on global advances made in physical, mathematical and biological sciences[47] and the value of these advances to Australia is approximately $330 billion.[48]

36 McKinsey Global Institute. (2018). *Skill Shift Automation and the Future of the Workforce*. https://www.mckinsey.com/~/media/McKinsey/Featured%20Insights/Future%20of%20Organizations/Skill%20shift%20Automation%20and%20the%20future%20of%20the%20workforce/MGI-Skill-Shift-Automation-and-future-of-the-workforce-May-2018.ashx

37 DIIS, Office of the Chief Economist. (2016). *Australian Innovation System report 2016*. https://www.industry.gov.au/data-and-publications/australian-innovation-system-report/australian-innovation-system-report-2016

38 Small and medium-sized enterprises (SMEs) are non-subsidiary, independent businesses which employ fewer than 200 employees, in accordance with ABS classifications. Palangkaraya, A., Spurling, T., & Webster, E. (2015). *Does Innovation Make SME Firms More Productive?* Centre for Transformative Innovation & Swinburne University. https://www.rba.gov.au/publications/confs/2015/pdf/palangkaraya-spurling-webster.pdf

39 AlphaBeta. (2020). *Australian Business Investment in innovation: Levels, Trends and Drivers*. https://www.industry.gov.au/sites/default/files/2020-02/australian-business-investment-in-innovation-levels-trends-and-drivers.pdf

40 Australian Bureau of Statistics. (2020). 8167.0 – *Characteristics of Australian Business, 2018-19*. https://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/8167.02018-19?OpenDocument

41 Andrews, D., Criscuolo, C., & Gal, P. (2015). *Frontier Firms, Technology Diffusion and Public Policy: Micro Evidence from OECD Countries (The Future of Productivity: Main Background Papers)* OECD. http://www.oecd.org/economy/growth/Frontier-Firms-Technology-Diffusion-and-Public-Policy-Micro-Evidence-from-OECD-Countries.pdf

42 DIIS, Office of the Chief Economist. (2016). *Australian Innovation System report 2016*. https://www.industry.gov.au/data-and-publications/australian-innovation-system-report/australian-innovation-system-report-2016

43 Solow, R. (1957). Technical Change and the Aggregate Production Function. *The Review of Economics and Statistics*. 39(3), 312-320.

44 See for example: Guellec, D. and van Pottelsberghe de la Potterie, B. (2001). R&D and Productivity Growth: Panel Data Analysis of 16 OECD Countries, *OECD Economic Studies No. 33*, OECD, Paris; Shanks, S. and Zheng, S. (2006). *Econometric Modelling of R&D and Australia's Productivity, Productivity Commission Staff Working Paper*, Canberra, April; Blanco, L., Prieger, J. and Gu, J. (2013). The Impact of Research and Development on Economic Growth and Productivity in the US States. *Pepperdine University, School of Public Policy Working Papers. Paper 48*. http://digitalcommons.pepperdine.edu/sppworkingpapers/48; Sokolov-Mladenovic, S. et, al. (2016). R&D expenditure and economic growth: EU28 evidence for the period 2002-2012, *Economic Research* 29(1), 1005-1020; Productivity Commission (2007). *Public Support for Science and Innovation, Research Report.* Productivity Commission, Canberra; AlphaBeta. (2019). *Australian business investment in innovation: levels, trends and drivers;* Industry Innovation and Science Australia (2017); DIIS, Office of the Chief Economist (2017*). Australian Innovation System Report* https://www.industry.gov.au/data-and-publications/australian-innovation-system-report/australian-innovation-system-report-2017

45 Australian Bureau of Statistics. (2019). 5260.0.55.002 - *Estimates of Industry Multifactor Productivity, 2018-19*. https://www.abs.gov.au/ausstats/abs@.nsf/mf/5260.0.55.002

46 Office of the Chief Economist. (2019). *Australian Innovation System Monitor.* Australian Department of Industry, Innovation and Science. https://www.industry.gov.au/data-and-publications/australian-innovation-system-monitor. Including externalities, Office of the Chief Economist (2019) states that R&D activity has been estimated to explain up to 75% of total factor productivity growth.

47 World Bank Open Data. (2018). https://data.worldbank.org/

48 World Bank Open Data. (2018). https://data.worldbank.org/

X-ray crystallography

Motivation: To discover the atomic structure of materials and understand their properties.

Type of innovation: Product and process.

Commercialisation path: Technology development, application deployed across different research fields, materials findings applied across multiple industries.

Impact: Underpins the development of almost all new materials used across several industries.

Scientists needed a way to see the structure of materials at the atomic level to reveal unknowns about their properties and understand the structure of living things. In 1913, building on earlier crystallography discoveries, Australians William and Lawrence Braggs discovered that using X-rays can allow scientists to determine the positions of atoms within a crystal and reveal its structure. The technique was improved and applied by other scientists throughout the 20th century solving for the structures of biological molecules and proteins, opening commercial pathways into health applications. The technology was also applied to non-biological materials and deepened understanding of their electrical and mechanical properties, opening commercial pathways into materials for all other industries seeking to improve their products and production methods. Crystallography underpins the development of almost all new materials and forms the backbone of developments across many industries such as pharmaceuticals, mining, agro-food, computer and electro-mechanical.[49] Examples of crystallography applications include analysing soils and salinization, studying the structure of plant proteins to develop more resistant crops, developing cures for animal and plant diseases, and studying bacteria important for the production of food products.[50] Leveraging the technology and applying the same method across numerous applications has accelerated product development across industries.

49 United Nations Educational, Scientific and Cultural Organisation. (2013). *Crystallography matters!* http://www.unesco.org/new/en/unesco/events/prizes-and-celebrations/celebrations/international-years/crystallography/brochure/

50 United Nations Educational, Scientific and Cultural Organisation. (2013). *Crystallography matters!* http://www.unesco.org/new/en/unesco/events/prizes-and-celebrations/celebrations/international-years/crystallography/brochure/

1.3.3 Creating social and environmental benefits

S&T innovation can also help businesses solve wider societal challenges and maintain their social licence to operate. According to the OECD, the ability to address issues such as climate change, health, food security and poverty depends on strong innovation and new forms of international collaboration.[51] If well-managed and used in conjunction with social innovation and other reforms, S&T advances can alleviate many of these societal challenges.[52]

S&T innovation also provides wide social benefits via increased living standards and quality of life. Over the last century, innovations have lowered the cost of goods and services and improved health outcomes for everyday Australians. The average number of work hours needed for an average Australian to purchase 1 litre of milk was 15 times larger in 1901 than today.[53] This combination of lower costs and higher quality outcomes is also true across sectors such as housing, healthcare and food. Even at the business level, innovating businesses are 3 times more likely to invest in employee professional development and 5 times more likely to make social contributions (donations, charity-work) than non-innovating businesses.[54]

1.3.4 Building resilience against external shocks

Globally, businesses face many risks including economic, environmental, geopolitical, societal and technological risks, and innovation can help build resilience and better manage these risks. The top 10 risks expected to increase in 2020 include frictions between major powers, protectionism regarding trade, economic recession, political issues, cyber-attacks, extreme heat waves, destruction of natural ecosystems, and uncontrolled fire.[56] S&T innovations that help manage these risks include advances in cybersecurity, low emission technologies, novel ways of managing and assessing the impacts of bushfires, and novel ways of monitoring and responding to biosecurity threats. In the case of bushfires, CSIRO's Data61 has developed *Spark*, an open framework for fire prediction and analysis. *Spark* models bushfire spread to help plan for and manage bushfires. This innovation helps improve decision-making in the areas of infrastructure planning, land management, firefighting resource allocation and deployment, decreasing the impact of fires on homes, businesses, infrastructure and people.[57]

PERC Solar Cells[55]

Motivation for innovation: Improve solar cell efficiency.

Type of innovation: Product (passivated emitter and rear cell (PERC) silicon solar cell).

Commercialisation path: R&D in Australia, commercialisation and manufacturing through Australian-Chinese joint ventures.

Impacts: 80% share of solar cell manufacturing capacity, flow-on benefits to Australia estimated over $8 billion, solar energy accounting for 8% of Australia's electricity in 2019, reduced greenhouse gas emissions and other hazardous gases.

Early solar technology had relatively low efficiency, and a solution was required to improve energy production from solar. In 1983, Australian Martin Green from the University of New South Wales invented the passivated emitter and rear cell (PERC), and his team improved efficiencies from 17% to 25%, breaking the world record for solar cell efficiency 18 times between 1983 and 2008. Solar costs were high until around 2005 when commercialisation and manufacturing became dominated by Australian-Chinese joint ventures. The industry rapidly adopted PERC technology from 2012 onwards as the solar industry pushed for higher performance. This technology has created significant value for Australia from energy efficiencies, reduction in greenhouse gas emissions and increased employment for rural areas. PERC solar cells make up over 80% of solar cell manufacturing capacity. The flow-on benefits to Australia were over $8 billion as at 2016, and solar energy accounted for 8% of Australia's electricity in 2019. Solar technology is one of the key technologies that will underpin the electricity grid of the future and is part of global decarbonisation efforts.

51 OECD. (2015). *The Innovation Imperative: Contributing to Productivity, Growth and Well-Being*. https://www.oecd.org/site/innovationstrategy/

52 OECD. (2015). *The Innovation Imperative: Contributing to Productivity, Growth and Well-Being*. https://www.oecd.org/site/innovationstrategy/

53 State Library Victoria. (2020). *What it used to cost.* https://guides.slv.vic.gov.au/whatitcost/groceries

54 DIIS, Office of the Chief Economist. (2016). *Australian Innovation System report 2016*. https://www.industry.gov.au/data-and-publications/australian-innovation-system-report/australian-innovation-system-report-2016

55 References for this case study: ALEO Solar. (n.d.). *PERC cell technology explained*. https://www.aleo-solar.com/perc-cell-technology-explained/; Blakers, A. (2019). Development of the PERC Solar Cell. *IEEE Journal of Photovoltaics*, 9(3), 629-635. doi:10.1109/JPHOTOV.2019.2899460; Blakers, A. (2020). *How an Aussie Invention could soon cut 5% of the world's greenhouse gas emissions*. https://theconversation.com/how-an-aussie-invention-could-soon-cut-5-of-the-worlds-greenhouse-gas-emissions-121571; Clean Energy Council. (2020). *Clean Energy Australia Report*. https://www.cleanenergycouncil.org.au/resources/resources-hub/clean-energy-australia-report; Green, M.A. (2015). The Passivated Emitter and Rear Cell (PERC): From conception to mass production. *Solar Energy Materials & Solar Cells*, 143, 190-197.; Green, M.A. (2016a). *Estimate of Economic Benefits to Australia of Past Australian Photovoltaic Research*. UNSW Australia. https://arena.gov.au/assets/2016/05/Info_Sheet_ACAP_1603_estimate-of-economic-impact_Final-Release-2.pdf; Green, M.A. (2016b). Revisiting the history books. *PV Magazine*. http://www2.pv.unsw.edu.au/martin-green-key-pv-publications/%5B7%5DRevisiting-the-history-books.pdf; Wenham, S. (2017). Hydrogenation a hundredfold solar cell booster shot. *Ecogeneration*. https://www.ecogeneration.com.au/hydrogenation-a-hundredfold-solar-cell-booster-shot/; Wood, T. et al. (2020). *Start with steel: A practical plan to support carbon workers and cut emissions*. Grattan Institute. https://grattan.edu.au/report/start-with-steel/; Clean Energy Council. (2020). *Clean energy at work study reveals enormous jobs opportunity*. https://www.cleanenergycouncil.org.au/news/clean-energy-at-work-study-reveals-enormous-jobs-opportunity

56 Oliver Wyman, Marsh & McLennan, Zurich Insurance Group and World Economic Forum. (2020). *The Global Risks Report 2020, Insights Report 15*th *Edition*. https://www.oliverwyman.com/our-expertise/insights/2020/jan/globalrisks2020.html

57 CSIRO, Data61. (n.d.). *Spark: Predicting bushfire spread*. https://data61.csiro.au/en/Our-Research/Our-Work/Safety-and-Security/Disaster-Management/Spark

The CSIRO Australian Centre for Disease Preparedness has been working on disease preparedness for decades. Current work undertaken during COVID-19 includes understanding the virus, forecasting the spread of the virus, vaccine development, building local capability and supply of medical materials, international collaboration in global response including sharing of best practice, reagents and materials, and being at the forefront of eHealth solutions.[58] Much of the current response activity builds on decades of planning, preparation and collaboration.

1.3.5 Spillover effects

Spillovers occur where the R&D activity of a business affects the profitability of other businesses or the well-being of consumers. Many studies have shown that innovation allows businesses to acquire knowledge created by others without needing to pay for it.[59] An Australian industry study shows that spillover effects are strongest between geographically close businesses, that R&D activity is higher in industrial clusters, and that higher education expenditure has a positive influence on business-level R&D expenditure.[60]

Google Maps[61]

Motivation: To improve the functionality and accessibility of online mapping services.

Type of Innovation: Product.

Commercialisation path: Programmed and developed by an Australian start-up, acquired by Google to further develop and commercialise.

Impacts: Most popular smartphone application in the world, accounts for 13% of all internet searches, estimated to earn USD 4.86 billion this year and predicted to earn USD 11 billion in 2023, as well as substantial spillover effects for industry and consumers.

Before Google Maps, navigation routes were not overlaid on top of a map, but rather, a separate list of directions that could be printed or written down. Earlier mapping services also required special software to operate and needed constant refreshing. Google Maps initially began as an application called Expedition, built from 2001 to 2003, by an Australian start-up, Where 2 Technologies. The company was acquired by Google to continue developing the technology where it was re-designed as an online platform and a downloadable application. The service is predicted to earn USD 4.86 billion in 2020 and over USD 11 billion in 2023. The full value of spillover effects of Google Maps to other industries is hard to quantify. Geospatial services reduce travel costs thanks to route planning, helping drive business sales by providing useful information and reviews, and helping businesses make strategic decisions about network and store locations. In a study of 22 countries (2016), geospatial services indirectly generated consumer benefits of over USD 550 billion, created 4 million direct and 8 million indirect jobs, improved revenues and costs by 5% for sectors that contribute 75% to global GDP, and numerous societal and environmental improvements through greater transport efficiency.

58 CSIRO. (n.d.) *Australian Centre for Disease Preparedness*. https://www.csiro.au/en/Research/Facilities/ACDP

59 Fung, K. (2006). Are Labor-Saving Technologies Lowering Employment in the Banking Industry?. *Journal of Banking & Finance*, 30(1), 179-198; Benavente, J. & R, Lauterbach. (2008). Technological Innovation and Employment: Complements or Substitutes? *The European Journal of Development Research*, 20(2), 318-329; Bloom, N., Schankerman, M., & Van Reenen, J. (2013). Identifying technology spillovers and product market rivalry, *Econometrica*, 81(4), 1347-1393; Elnasri, A & Fox, K.J. (2017). The contribution of research and innovation to productivity, *Journal of Productivity Analysis*, 47(3), 291-308.

60 Bakhtiari, S. & Breunig, R. (2017). *The role of spillovers in research and development expenditure in Australian Industries*. Office of the Chief Economist. https://www.industry.gov.au/data-and-publications/staff-research-papers/the-role-of-spillovers-in-research-and-development-expenditure-in-australian-industries

61 References for this case study: AlphaBeta (2016). *The Economic Impact of Geospatial Services: How Consumers, Firms and Society Benefit from Location-Based Information*, https://www.alphabeta.com/our-research/the-economic-impact-of-geospatial-services-how-consumers-businesses-society-benefit-from-location-based-information/; Carlson, N. (2012). To Do What Google Does In Maps, Apple Would Have To Hire 7,000 People. *Business Insider*. https://www.businessinsider.com.au/to-do-what-google-does-in-maps-apple-would-have-to-hire-7000-people-2012-6; Chivers, T. (2013). The story of Google Maps. *The Telegraph*. https://www.telegraph.co.uk/technology/google/10090014/The-story-of-Google-Maps.html; El Khoury, R. (2019). Google Maps hits 5 billion downloads on the Play Store, does it after YouTube but before the Google app. *Android Police*. https://www.androidpolice.com/2019/03/09/google-maps-hits-5-billion-downloads-on-the-play-store-does-it-after-youtube-but-before-the-google-app/; Fishkin, R. (2018). New Jumpshot 2018 Data: Where Searches Happen on the Web (Google, Amazon, Facebook, & Beyond). *SparkToro*. https://sparktoro.com/blog/new-jumpshot-2018-data-where-searches-happen-on-the-web-google-amazon-facebook-beyond/; Gannes, L. (2015). Ten Years of Google Maps, From Slashdot to Ground Truth. *Vox*. https://www.vox.com/2015/2/8/11558788/ten-years-of-google-maps-from-slashdot-to-ground-truth; Hutcheon, S. (2015) The Untold Story About The Founding of Google Maps. *Medium*. https://medium.com/@lewgus/the-untold-story-about-the-founding-of-google-maps-e4a5430aec92.; Nahar, A. (2017). Google Maps – the most expansive data machine. *Harvard Business School Digital Initiative*. https://digital.hbs.edu/platform-digit/submission/google-maps-the-most-expansive-data-machine/; Popper, B. (2017). Google announces over 2 billion monthly active devices on Android. *The Verge*. https://www.theverge.com/2017/5/17/15654454/android-reaches-2-billion-monthly-active-users; Schaal, D. (2019). Google Maps Poised to Be an $11 Billion Business in 4 Years. *Skift*. https://skift.com/2019/08/30/google-maps-poised-to-be-an-11-billion-business-in-4-years/; Smith, C. (2013). Google+ Is The Fourth Most-Used Smartphone App. *Business Insider Australia*. https://www.businessinsider.com.au/google-smartphone-app-popularity-2013-9?r=US&IR=T#infographic; Taylor, B. (2005). Mapping your way. *Official Google Blog*. https://googleblog.blogspot.com/2005/02/mapping-your-way.html; Transparency Market Research. (2018). *Digital Map Market*. https://www.transparencymarketresearch.com/digital-map-market.html

1.3.6 International competitiveness

Innovation can boost international competitiveness in export markets and international reputation. Businesses that engage in innovation are more productive and competitive than non-innovating businesses.[62] Similarly, countries that engage and invest in innovation are also more likely to be at the forefront of the technology frontier and thus more likely to have a competitive advantage in the invention and export of new products and processes compared to less innovating countries.[63] By demonstrating S&T innovation leadership, Australian businesses can also foster cross-border partnerships and collaborations, and this can enhance diplomatic relations and improve trade outcomes.

Demonstrating the international competitiveness of Australian canola[64]

Motivation: To secure access to European Union (EU) canola markets after legislative amendments imposed additional requirements on biofuels.

Type of innovation: Process.

Commercialisation path: Early research by the CSIRO, and a lifecycle assessment undertaken by various public and private Australian organisations.

Impact: $2.5 billion of canola exported to the EU since report acceptance, robust environmental measurement techniques and repeatable methodology that can be applied across the grain sector to understand supply chains and further emissions reductions.

The EU biofuels market is the largest market for Australian canola, particularly non-genetically modified canola. In January 2018, a revision to the European Union Renewable Energy Directive meant only biofuels with a minimum 50% reduction in greenhouse gas (GHG) emissions compared to fossil fuels would be accepted into the EU market. Dr Sandra Eady of CSIRO in partnership with Tim Grant of LifeCycles developed the Life Cycle Inventory of Australian agriculture which underpinned a report to the EU demonstrating Australian compliance with the new directive and thus securing the export market for Australia. Since the acceptance of the report to mid-2019, the value of canola exported to the EU exceeded $2.5 billion. The initiative also provided flow-on political benefits and a robust life cycle assessment framework for other Australian grain producers that allows them to meet new sustainability demands of the agricultural sector.

62 DIIS, Office of the Chief Economist. (2016). *Australian Innovation System report 2016*. https://www.industry.gov.au/data-and-publications/australian-innovation-system-report/australian-innovation-system-report-2016

63 Porter, M. (1990). *Competitive Advantage of the Nations*. New York, Free Press; Schwab, K. (2019). *The Global Competitiveness Report 2019*. *World Economic Forum*. http://www3.weforum.org/docs/WEF_TheGlobalCompetitivenessReport2019.pdf; OECD. (2007). *Innovation and Growth: Rationale for an Innovation Strategy*, https://www.oecd.org/science/inno/39374789.pdf

64 References for this case study: Kaur, H. (2019). *Maintaining access to EU markets for Australian canola*. CSIRO.; Koreis, D. (2017). *Australia secures $1.0 billion EU canola export market*. CSIRO. https://www.csiro.au/en/News/News-releases/2017/Australia-secures-$1-billion-EU-canola-export-market.; Roth, I. (2018). *European Canola Market Fact Sheet*. Grains Research and Development Corporation. https://grdc.com.au/__data/assets/pdf_file/0029/295625/European-Canola-Market-Fact-sheet.pdf?utm_source=website&utm_medium=download_button&utm_campaign=pdf_download&utm_term=National;%20North;%20South;%20West&utm_content=European%20Canola%20Market

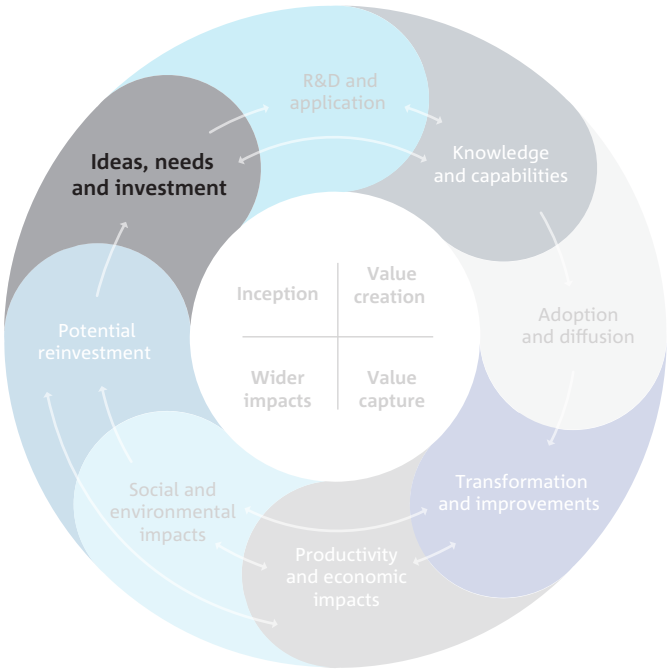
2 Challenges and opportunities

Translating science and technology into impact requires skilful navigation of the innovation cycle. This chapter draws on interviews and research to identify major challenges and opportunities for Australian businesses.

It is clear from the literature and stakeholder consultations that translating research into impact and realising value from S&T investment requires significant work and coordination across many actors in the innovation system. Several challenges hinder navigation through the innovation cycle and prevent businesses from maximising the economic, social and environmental impacts from S&T innovation. These include declining business investment in S&T innovation; a lack of translation of high-quality research into development and commercial outputs; gaps in skills, knowledge and capabilities; low adoption of overseas innovations and diffusion; and environmental and social costs.

As the national science agency and a connector between research and industry, CSIRO sees several major opportunities for businesses to overcome the current challenges and capture more value from S&T innovation in Australia. To address low business investment, businesses can collaborate with research institutions, government and the community sector to agree on shared mission-oriented S&T innovation and strategically target investment in what will be a constrained investment environment for some time to come. To shift innovations from inception to full commercialisation, collaboration is also key, forging enduring connections throughout the innovation cycle, creating closer links between the early stages of S&T innovation, and realising innovation impacts on wider on society, the economy and environment.
To address workforce gaps, businesses can directly support upskilling and continuous work-based learning, and improve collaboration with educational institutions to shape the supply of skilled graduates in a way that aligns with industry's innovation and technology goals.[65] To improve innovation adoption, businesses can engage in non-R&D innovation, such as new business models, to support the uptake of new technologies, and can develop clusters of innovation activity.

2.1 Business investment



2.1.1 Challenge: Declining business investment

One of the key challenges identified through desktop research and consultation, is that overall investment in R&D innovation is declining. While this is the case for both government and business investment in R&D, the decline in business investment is more acute.

National gross expenditure on R&D (GERD) as a percentage of GDP declined from 2.3% in 2008-09 to 1.8% in 2017-18,[66] and Australia's GERD is low compared with the international benchmark for innovative economies of at least 3% annually.[67] Australian GERD per capita is below the OECD average and behind similarly sized economies, such as Belgium and the Netherlands (see Figure 5). Business expenditure on R&D (BERD) in particular has declined by 30% over the past decade.[68] BERD relative to GDP declined continuously from 1.22% in 2011-12 to 0.9% in 2017-18; having the greatest impact on national innovation investment, since BERD constitutes the largest share of GERD.[69]

65 Industry Innovation and Science Australia. (2020). *Stimulating business investment in innovation*. https://www.industry.gov.au/data-and-publications/stimulating-business-investment-in-innovation

66 Australian Bureau of Statistics. (2019). 8104.0 - *Research and Experimental Development, Firms, Australia, 2017-18* [Latest release]. https://www.abs.gov.au/AUSSTATS/abs@.nsf/Latestproducts/8104.0Main%20Features22017-18?opendocument&tabname=Summary&prodno=8104.0&issue=2017-18&num=&view=

67 Industry Innovation and Science Australia. (2016). *Performance Review of the Australian Innovation, Science and Research System*. https://www.industry.gov.au/sites/default/files/2018-10/performance-review-of-the-australian-innovation-science-and-research-system-isa.pdf

68 AlphaBeta. (2020). *Australian Business Investment in innovation: Levels, Trends and Drivers.* https://www.industry.gov.au/sites/default/files/2020-02/australian-business-investment-in-innovation-levels-trends-and-drivers.pdf

69 Australian Bureau of Statistics. (2019). 8104.0 - *Research and Experimental Development, Firms, Australia, 2017-18* [Latest release]. https://www.abs.gov.au/AUSSTATS/abs@.nsf/mf/8104.0/

Weakening and patchy investment in innovation constricts activity along the entire innovation cycle; preventing new ideas, improvements and exciting ventures, and limiting investors' ability to realise value from existing investments. Without concerted action, this is likely to continue, with the impacts of COVID-19 further reducing revenues available and disincentivising investors from allocating remaining revenues towards R&D.

Stakeholders attributed these challenges to three main causes:

1. A lack of research-industry **collaboration** to develop and pursue strategic investment priorities in S&T innovation. Stakeholders stressed that innovators, including those across the research-industry connection, do not share a collective innovation purpose. As a result, Australian investment in innovation is currently not targeted to long term goals, such as building resilient national capabilities, maximising comparative and competitive advantages or addressing future challenges.
2. **Market failures** (such as externalities) prevent the private sector from capturing all the benefits from their investments in innovation. For example, despite their beneficial effects, spillovers can also disincentivise private sector investment in R&D as the investor shares the benefit with others that did not contribute to the investment or share the risk (free riders).[70] The weak economic environment seen over the past decade and now acutely felt under COVID-19 will continue to compound these disincentives to invest.
3. Declining overall investment and demand for innovation indicates some degree of cultural **risk-aversion**, an under-confidence in innovating potential, and a sense of complacency that limits bold investments.[71] Industry Innovation and Science Australia also highlights a national tendency toward short-termism at the expense of progress towards a more innovative and dynamic future.[72]

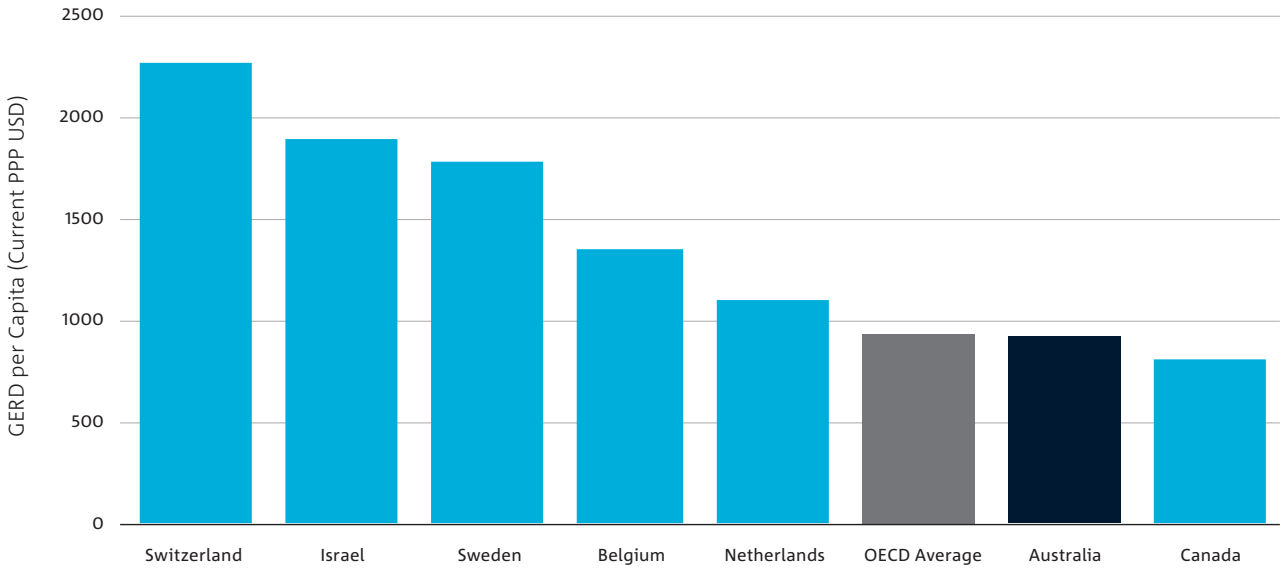


Figure 5: 2017 Gross Expenditures on R&D per capita

Data source: OECD, Gross domestic spending on R&D https://data.oecd.org/rd/gross-domestic-spending-on-r-d.htm

70 Ben Westmore. (2014). Policy incentives for private innovation and maximising the returns. *OECD Journal: Economic Studies*. 2013(1). https://www.oecd.org/economy/policy-incentives-for-private-innovation-and-maximising-the-returns.pdf

71 Green, R. & Howard, J. H. (2015). *Australia's Innovation Future: A Report on the Structure and Performance of Australia's National Innovation System.* www.aph.gov.au/Parliamentary_Business/Committees/Senate/Economics/Innovation_System/~/media/Committees/economics_ctte/Innovation_System/Final_Report/e05. pdf.

72 Industry Innovation and Science Australia. (2016). *Performance Review of the Australian Innovation, Science and Research System*. https://www.industry.gov.au/sites/default/files/2018-10/performance-review-of-the-australian-innovation-science-and-research-system-isa.pdf

2.1.2 Opportunity: Develop shared innovation purpose and targeted investment

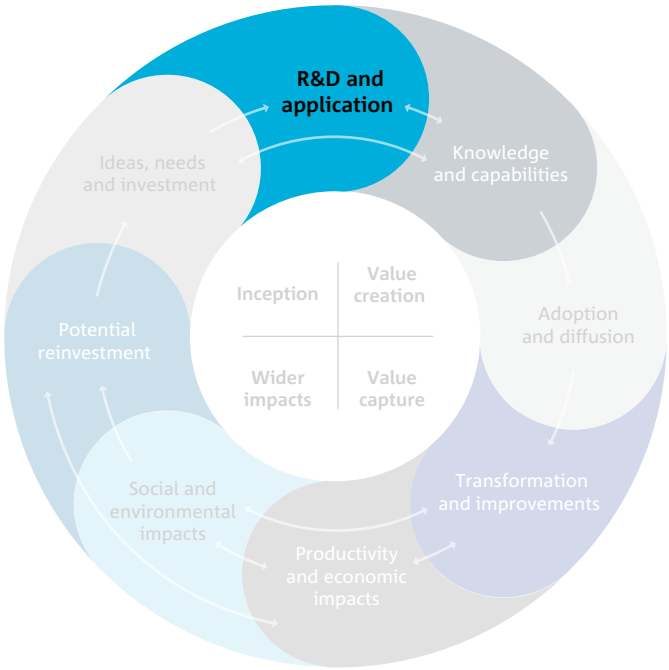
Businesses, in collaboration with research organisations, can create purposeful, impactful and strategically balanced approaches that better encourage investment in innovation. These approaches can encourage increasing investment and more efficiently allocating existing investment. They can also seize emerging market and technological opportunities in areas of comparative and competitive advantage. Australian businesses can extend beyond traditionally competitive sectors (mining, agriculture, education and tourism) and strategically diversify their focuses to increase economic complexity, support emerging industries and carve out niches in global value chains. There are considerable short, medium and long term growth opportunities in advanced technological industries such as advanced manufacturing, medical technologies and quantum technologies, which directly address social needs in areas of health, food and sustainability.[73] CSIRO economists and others have estimated the size of some of these growth opportunities.[74]

Mission-led innovation

Several of the experts consulted emphasised the potential for national level purposeful or 'mission-led innovation', whereby industry, research organisations, government and the community work together to solve major challenges facing society using measurable goals.[75] CSIRO also pursues mission-led innovation, including identifying six challenges to solve using innovative S&T,[76] and more recently announcing missions.[77] However, mission-led innovation extends beyond any single organisation, and involves all stakeholder groups building collaborative networks across industry, government, research organisations and community.

To help mitigate market failure and risk-aversion associated with innovation, all stakeholder groups can also participate in the allocation of risks and rewards.[78] De-risking involves increasing capital and support for innovative ventures to catalyse virtuous cycles of innovation and growth, via financing arrangements such as staging, management, pooling risk, and other strategies for managing downside risk. The rationale for this investment is that in some cases, innovation takes decades while others take a short series of swift incremental improvements.[79] As such, investment strategies should be long-term and tied to farsighted national capabilities and social impacts; a point that expert consultations consistently emphasised.

2.2 Commercialising R&D



2.2.1 Challenge: High-quality research but under-development and commercialisation

Australia has a productive science and research sector in terms of high-quality technical research. The GII 2020 ranked Australia 15th for overall R&D; 11th for scientific and technical publications relative to GDP; 9th for human capital and research; and 10th for citable documents per publication; all classified as country strengths.[80] However, Australia's R&D strengths are on the research side rather than in development and commercialisation.[81] In other words, while Australia is strong in research, it has not been as successful in shifting technologies from the research lab to industrial scale-up. Deriving value from investment requires moving proven technologies to pilot demonstrations, small commercial trials, and finally large-scale commercial deployment.

73 See for example CSIRO Industry Roadmaps, https://www.csiro.au/en/Do-business/Futures/Reports/Future-Industries; McKinsey. (2014). *Compete to Prosper: Improving Australia's Global Competitiveness*. https://www.mckinsey.com/featured-insights/asia-pacific/compete-to-prosper-improving-australias-global-competitiveness

74 CSIRO. (2017). *Growth opportunities for Australian food and agribusiness*. https://www.csiro.au/en/Do-business/Futures/Reports/Ag-and-Food/Opportunities-for-Food-and-Agribusiness; CSIRO. (2020). *Growing Australia's Quantum Technology Industry*. https://www.csiro.au/en/Showcase/quantum; AlphaBeta. (2018). *Digital Innovation: Australia's $315B Opportunity*. https://data61.csiro.au/en/Our-Research/Our-Work/Future-Cities/Planning-sustainable-infrastructure/Digital-Innovation

75 Popularised by Mariana Mazzucato and now widely used in Europe and the UK. https://marianamazzucato.com/research/mission-oriented-innovation-policy/; https://www.interregeurope.eu/policylearning/news/5970/grand-challenges-the-new-mission-oriented-innovation-frontier/

76 See the six challenges CSIRO is currently tackling at https://www.csiro.au/en/About/Strategy-structure/Solving-the-greatest-challenges

77 CSIRO. (2020, August 12). *Mission possible – A vision for Australia's recovery and future resilience* [Press release]. https://www.csiro.au/en/News/News-releases/2020/Speech-to-the-National-Press-Club

78 Mazzucato, M. (2018). The Value of Everything

79 Adner, R. and Kapoor, R. (2016). Right Tech, Wrong Time. *Harvard Business Review*. November 16 Issue

80 Global Innovation Index. (2020). *Australia – Economy analysis*. https://www.globalinnovationindex.org/analysis-economy; The GII is one many international assessment tools that combines disparate metrics into a single score or ranking. While there are methodological challenges from this process, the index provides a useful annual pulse check on innovation performance.

81 DIIS, Office of the Chief Economist. (2016). *Australian Innovation System Report*.

Australia's innovation efficiency (measured as the ratio of innovation inputs to outputs) is low and reflects the challenges in commercialising cutting-edge research. While the GII ranks Australia a high 13th on innovation inputs in 2020, this does not translate into innovation outputs, for which Australia ranked only 31st globally and 39th for patents relative to GDP.[82] Among the top five patent applicants in 2019, gambling machine manufacturer Aristocrat filed 96 patents, followed by CSIRO with 47, the University of Sydney with 19, NewSouth Innovations with 17 and the University of Queensland with 14.[83] The top-ranking international applicants were mobile communication equipment manufacturers Oppo, Qualcomm, LG Electronics and Huawei plus Chinese e-retailer Alibaba Group.[84] Since patenting is one of the ways used to protect the competitive advantages that come with innovation, these statistics also indicate that Australia has challenges with capturing the value of applied research across the economy.

Figure 6 demonstrates that while Australia performs well in innovation inputs globally, its performance drops when it comes to most innovation outputs, particularly innovation linkages and knowledge absorption, creation and diffusion. Although Australia's performance on knowledge impact is better than its performance on other outputs, there is still significant room to improve.

Innovation novelty is important for business performance. For instance, a survey of ASX businesses shows that novel innovation explains the difference in performance between top-performing and average-performing businesses.[85] Top performing businesses also achieve and sustain their position by delivering market-leading innovations and engaging in business model innovation.[86] However, in Australia, only 11% of innovating businesses (and 42% of R&D-innovating businesses) develop novel innovations, with the diffusion of innovations already developed by others accounting for the vast majority of reported innovations. This figure is relatively poor compared to Australia's peers such as Canada, France and New Zealand.[87]

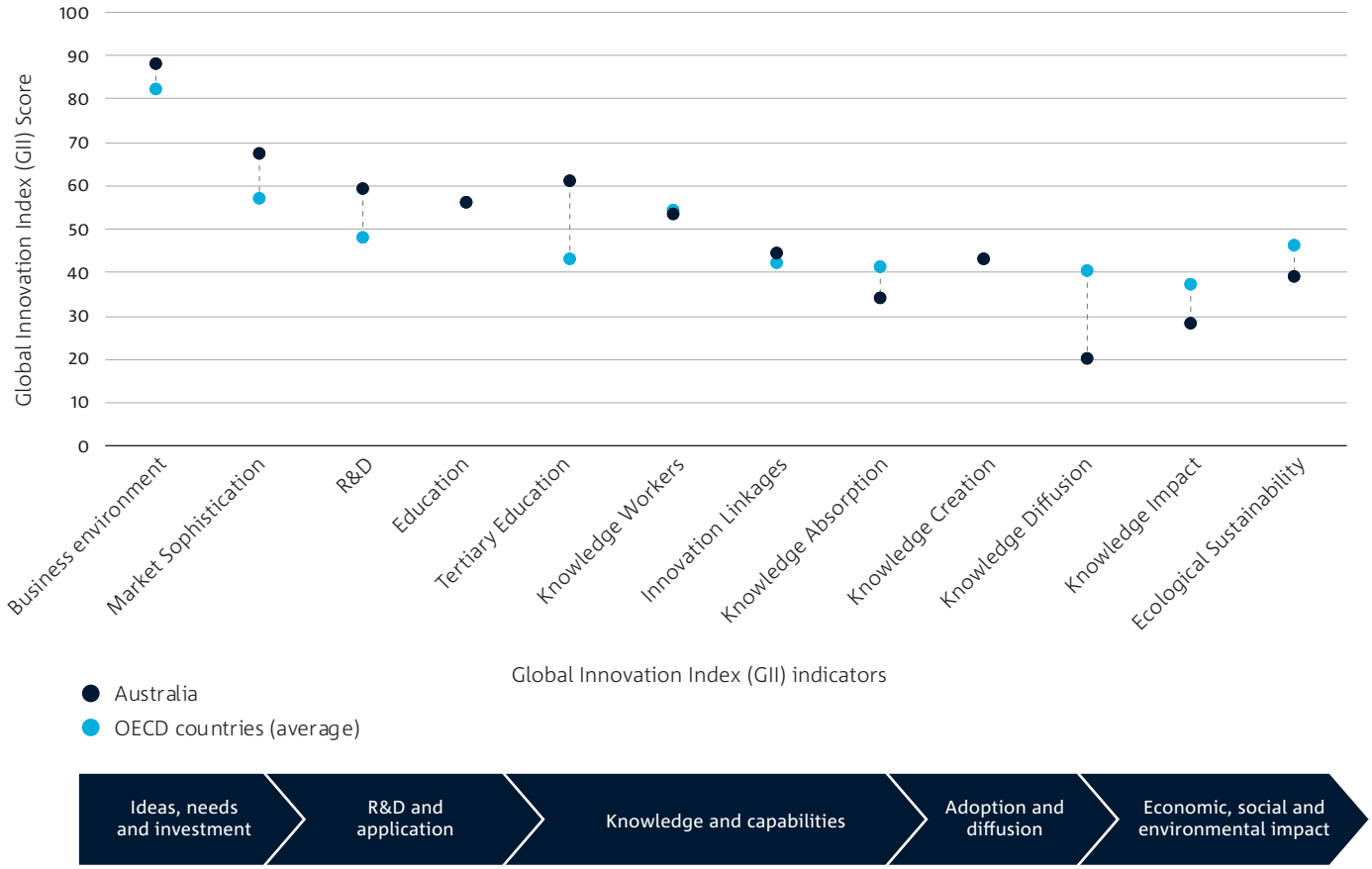


Figure 6: Key Performance Indicators across the Innovation Cycle, Australia compared to the OECD

Data Source: Global Innovation Index. https://www.globalinnovationindex.org/analysis-indicator

82 Global Innovation Index. (2020). *Australia – Economy analysis*. https://www.globalinnovationindex.org/analysis-economy

83 IP Australia. (2020). *IP Report 2020: Chapter 2 – Patents*. https://www.ipaustralia.gov.au/ip-report-2020/patents

84 IP Australia. (2020). *IP Report 2020: Chapter 2 – Patents*. https://www.ipaustralia.gov.au/ip-report-2020/patents

85 Ford JA and Brea E (2020). *Thriving Through Innovation: Lessons From the Top*. CSIRO, Australia

86 Ford JA and Brea E (2020). *Thriving Through Innovation: Lessons From the Top*. CSIRO, Australia

87 The Canada figures are 21% and 46%, France 20% and 58%, and New Zealand 15% and 48%. OECD. (2019). *Business innovation statistics and indicators*. https://www.oecd.org/sti/inno/inno-stats.htm

Australia is traditionally weak in collaborating on across various parts of the innovation system, making it more difficult to ensure innovation investments create products that are readily adopted by users. Although collaboration within the research sector is strong,[88] there is poor collaboration between it and industry, with insufficient researchers working in industry, insufficient co-patenting and co-authorships, and insufficient incentives for researcher and industry collaboration.[89] Among 38 OECD countries, Australia ranked 27th for the percentage of publications that have industry co-authors.[90] Globally, the GII 2020 ranked Australia 39th for collaboration and ideas sharing between businesses and research organisations; and 44th on researchers working in businesses, with Australia scoring poorly even among similarly sized economies.[91] Only 2% of Australian businesses collaborate on innovation with higher education or government institutions, compared with the OECD average of 14%, ranking Australia last in the OECD.[92] Collaboration is particularly challenging for SMEs, which may not have access to information about end user's needs, path to market and potentially useful science or technologies. In 2018-19, while 18% of large innovation-active businesses collaborated for innovation, only 14% of SMEs did on average.[93] In Australia, around 30% of researchers are based in industry,[94] compared with 80% in Korea, 73% in Japan and 71% in the US.[95] Embedding researchers within businesses is an effective way to increase the number of researchers in industry and stimulate researcher-to-business collaboration.

Internationally, Australia's relatively small size means it cannot specialise in everything and so collaboration is critical to ensure Australia's innovations are impactful and can contribute to and learn from others' advancements. Despite this, only 7% of Australia's innovation-active businesses engaged in international collaboration,[96] and Australia ranked 84th globally for GERD financed by foreign partners.[97] Interestingly, non-innovative businesses were more likely to operate in international markets (29%) than innovative businesses (20%), suggesting that there is room to boost the share of innovative businesses to increase industry participation in global value chains.[98]

These challenges are driven by factors relating to the disconnectedness of Australia's innovation systems:

1. Low innovation inputs indicate there are systemic challenges in **aligning S&T research** with public and social needs, and market demand.[99] To attract the necessary resources and investment for successful development and application, end-user needs and preferences must be the starting point, and this knowledge has to be shared effectively across the value chain. Difficulties arise when pathways from research to commercialisation and markets are unclear.

2. **Cultural factors** also contribute to value chain disconnectedness, such as a low appetite to develop 'blockbuster innovation' or moon-shot technologies that incur high rates of risk, returns and investment. Often developing innovations and creating new ventures requires high risk borne by founders and investments with so-called 'skin in the game'; signalling to others that the venture is worth supporting. Purely academic KPIs for researchers (such as publishing papers) rather than a balance with industry collaboration or commercialisation measures, hinders incentives to connect research and application.

Although research need not immediately create value and impact –noting the importance of basic research to build vital knowledge foundations – Australia's significant difficulties in translating research into development and wider applications incurs a significant opportunity cost in terms of innovation forgone. A weakly networked innovation system[100] - domestically and internationally – limits the value captured from research in terms of new and improved Australian products and services that could build competitive advantage as well the ability to contribute to and learn from advancements elsewhere.

88 DIIS, Office of the Chief Economist. (2016). *Australian Innovation System Report*.

89 DIIS, Office of the Chief Economist. (2016). *Australian Innovation System Report*; 20% of innovation-active firms reported having insufficient funds for collaboration. Source: Australian Bureau of Statistics. (2020). 8167.0 – *Characteristics of Australian Business, 2018-2019.*

90 Industry Innovation and Science Australia. (2016). *Performance review of the Australian innovation, science and research system*. ISA, Canberra.

91 Global Innovation Index. (2020). *Australia – Economy analysis*. https://www.globalinnovationindex.org/analysis-economy

92 OECD. (2017). *Innovation Indicators,* OECD Publishing; Office of the Chief economist. (2019). Australian Innovation System Monitor. https://publications.industry.gov.au/publications/australianinnovationsystemmonitor/index.html

93 Australian Bureau of Statistics. (2020). *Characteristics of Australian Businesses, 2018-19*. https://www.abs.gov.au/statistics/industry/technology-and-innovation/characteristics-australian-business/latest-release#data-download

94 Note: Software developers or programmers; and executives and directors involved in the planning or management of scientific and technical aspects of R&D projects are also classified as researchers (BERD) and postgraduate students are classified as researchers (HERD, 2016). Source: ABS, 8104.0 – Research and Experimental Development, Businesses, Australia, 2017–18; 8109.0 – Research and Experimental Development, Government and Private Non-Profit Organisations, Australia, 2016–17; 8111.0 – Research and Experimental Development, Higher Education Organisations, Australia, 2016.

95 OECD. (2016). *Main Science and Technology Indicators*. https://stats.oecd.org/Index.aspx?DataSetCode=MSTI_PUB (Accessed 30 June 2020).

96 OECD. (2019). *Business innovation statistics and indicators*. https://www.oecd.org/sti/inno/inno-stats.htm

97 Global Innovation Index 2019 Database. https://www.globalinnovationindex.org/analysis-indicator

98 OECD. (2019). *Business innovation statistics and indicators*. https://www.oecd.org/sti/inno/inno-stats.htm

99 Mormina, M. (2019). Science, technology and innovation as social goods for development: rethinking research capacity building from Sen's capabilities approach. *Science and engineering ethics*, 25(3), 671-692.

100 Except for resource sectors. Source: DIIS, Office of the Chief Economist. (2016). *Australian Innovation System Report*.

2.2.2 Opportunity: Focus more on applied R&D and collaboration

Improving Australia's performance in applied R&D requires solutions-focused research, collaboration between public, private, social and research sectors, and cultural change. Understanding relevant societal or market needs, and the variety of suitable pathways for wide application or commercialisation is foundational to supporting innovation.

Solutions-focused research for improved development

According to stakeholders, investment in R&D needs to be supported by incentives that encourage solutions through to commercial and broader applications, rather than focusing exclusively on the nature of problems. R&D intensive sectors where Australia has clear comparative advantages (mining, agriculture, healthcare, finance and education)[101] needs focused investment that is in line with a clear, purposeful strategy. Such R&D investment has a considerable rate of return, with several studies estimating a private return of 10-30% and social returns of more than 40%.[102] These returns and business performance can be optimised when investment in non-R&D (including incremental improvements and digital capabilities) and intangible assets such as intellectual property complement R&D.[103]

Stakeholders also underscored the need for consistent and effective incentives to encourage effective research-to-research collaboration by creating denser webs of communication between distinct research areas, researchers and businesses. Many stakeholders considered the R&D tax incentive (RDTI) as vital for promoting innovation.[104]

Promote industry-research links and collaboration over competition

Strengthening collaboration between industry and the research sector is a leading opportunity for improving Australia's value capture from innovation. A CSIRO and University of Queensland 2020 survey of ASX businesses found that the top-performing businesses collaborate broadly across several channels, including with suppliers and customers, university partners, and public and private research organisations. Breadth of collaboration was a key driver of these businesses' performance and was 11 times higher for the top-performing businesses compared to the average-performing businesses.[105] An analysis from Swinburne University of Technology also found that engaging in collaborative research raised a business's likelihood of undertaking innovation by 4.4 percentage points.[106]

Partnerships, engagement programs and activities that combine industry and researchers to jointly find solutions to challenges facing industry and wider society is foundational to effective industry-research collaboration. Businesses and researchers can engage in co-invention throughout the innovation cycle.[107] Collaboration strategies that already exist in Australia but which merit promotion and increased support include researcher industry placements, co-led start-up initiatives and accelerator programs, research sector spin-offs, and cross-sector digital information-sharing platforms.[108] These collaboration strategies can build stronger bridges between Australia's high-quality research and its evolving industries as it moves towards a more innovation-driven future.

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101 World Integrated Trade Systems. (2017) *Revealed comparative advantage*. https://wits.worldbank.org/CountryProfile/en/country/by-country/startyear/LTST/endyear/LTST/tradeFlow/Export/indicator/RCA/partner/WLD/product/Total

102 DIIS, Office of the Chief Economist. (2016). *Australian Innovation System Report*, Office of the Chief Economist, Australian Department of Industry, Innovation and Science

103 AlphaBeta. (2020). *Australian Business Investment in innovation: Levels, Trends and Drivers*. https://www.industry.gov.au/sites/default/files/2020-02/australian-business-investment-in-innovation-levels-trends-and-drivers.pdf

104 An AusBiotech survey of the life sciences industry found that 63% of respondents were materially influenced to undertake R&D based on the RDTI. Source: AusBiotech (2019). R&D Tax Incentive: Additionality and spillovers for the life sciences industry. A comparable CIE study found that about one third of R&D spending decisions were materially influenced by the RDTI. Source: Centre for International Economics, R&*D Tax Incentive Programme Review*, prepared for the Department of Industry, Innovation and Science, 29 March 2016, p. 88. See also Ferris, B., Finkel, A., Fraser, J. (2016). *Review of the R&D Tax Incentive*. Department of Industry, Commonwealth of Australia. https://www.industry.gov.au/sites/default/files/May%202018/document/pdf/research-and-development-tax-incentive-review-report.pdf?acsf_files_redirect

105 Ford JA and Brea E (2020). *Thriving Through Innovation: Lessons From the Top*. CSIRO, Australia

106 Palangkaraya, A., Spurling, T. & Webster, E. (2018). *What drives firm innovation? A review of the economics literature.* Centre for Transformative Innovation, Swinburne University of Technology

107 For a collection of work on user-led, cross-sector innovation refer to: Hippel, E. (2020). Section 1: Innovation and innovation motivations by users and lead users, https://evhippel.mit.edu/papers/section-1/; Von Hippel, E. (2009). Democratizing innovation: the evolving phenomenon of user innovation. *International Journal of Innovation Science*, 1(1), 29-40.

108 DIIS, Office of the Chief Economist. (2016). *Australian Innovation System Report*, Office of the Chief Economist, Australian Department of Industry, Innovation and Science

Creating stronger cross-sector linkages throughout the innovation cycle can also improve R&D effectiveness by translating the research into commercial outcomes and successful new products.[109] Scientists making new inventions have deep technical knowledge but not always the business experience or skills to successfully commercialise their discoveries themselves. Similarly, entrepreneurs who recognise a social or market opportunity and are willing to bear necessarily high levels of risk, do not always have sufficient access to technical advice. Australia's disconnect between the research sector and industry reflects a missing 'market for judgment': the ability to determine what to do versus what not to do.[110] Forging stronger connections between researchers and entrepreneurs across the full spectrum of the innovation cycle would improve the development side of R&D, share the risks, reduce the barriers to commercialisation and promote wider applications and impact of ground breaking innovations.[111]

Looking beyond borders, there is great value to be captured by focusing on international collaboration rather than competition. Across sectors, Australian businesses can move away from their often secretive, proprietary culture, and instead, position themselves in high-value niches within global value chains and extend international partnerships. Innovation conducted via international collaboration produces more innovations, which in turn increases Australian businesses' share in global markets and productivity growth.[112] Businesses with greater international exposure tend to grow or maintain market shares, innovate more, improve management quality and enjoy doubled productivity growth compared to businesses with low international exposure.[113] The higher rate of success of non-innovation active businesses in the international markets could provide lessons for innovation active businesses that wish to expand to global markets.[114]

Non-innovation active businesses that are already engaged in international markets could also be advised and supported to become innovation active and expand their global market share. Effective collaboration will require a deep understanding of international partner goals and market drivers, which is achieved by actively forging international relationships and contributing to international research efforts.[115] Accordingly, Australia's innovation strategies should incorporate international collaboration objectives as part of its national missions and capabilities.

Promote a 'growth through innovation' culture

Finally, overcoming collaboration challenges throughout Australia's innovation system requires a fundamental cultural shift from a siloed 'commodity culture' to an innovation culture based on strong relationships and a value-added growth focus.[116] A CSIRO and University of Queensland 2020 survey of ASX businesses, found that corporate entrepreneurship was the strongest cultural predictor of business performance, with top-performing businesses showing a willingness to take risks, a propensity to change product lines (innovativeness), and a proactiveness to be assertive with competition.[117]

In its report on stimulating business investment in innovation, Industry Innovation and Science Australia recommends promoting a 'growth through innovation' mindset among leadership and key stakeholders, which emphasises innovation as a leading strategy for serving public need while growing profitability and competitiveness.[118] This mindset recognises the vast opportunities presented by cross-sector collaboration and the role that innovation plays in building on comparative advantage via more productive use of resources.[119] During expert consultations, the importance of shifting culture in favour of innovation was also emphasised as necessary to address many of Australia's social and economic challenges. Working toward a national culture of innovation also complements ambitious national missions.[120]

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109 Industry Innovation and Science Australia (2019*). Australia 2030: Prosperity through Innovation (attached) and Australian Government response to Innovation and Science Australia: Australia 2030,* https://www.industry.gov.au/data-and-publications/australia-2030-prosperity-through-innovation

110 Gans, J. & Leith, A. (2019). *Innovation + Equality*. MIT Press.

111 OECD. (2010). *The OECD innovation strategy: getting a head start on tomorrow*. OECD Publishing

112 DIIS, Office of the Chief Economist. (2014). *Australian Innovation System Report*; DIIS, Office of the Chief Economist (2016). *Australian Innovation System Report*.

113 McKinsey (2014). *Compete to Prosper: Improving Australia's Global Competitiveness*. https://www.mckinsey.com/featured-insights/asia-pacific/compete-to-prosper-improving-australias-global-competitiveness

114 OECD. (2019). *Business innovation statistics and indicators*. https://www.oecd.org/sti/inno/inno-stats.htm

115 Green, R., & Howard, J. H, (2015). *Australia's Innovation Future: A Report on the Structure and Performance of Australia's National Innovation System.* https://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Economics/Innovation_System/~/media/Committees/economics_ctte/Innovation_System/Final_Report/e05.pdf; Senate Economics Reference Committee. (2015). Senate inquiry report, December 2015. https://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Economics/Innovation_System/Report

116 Green, R., & Howard, J. H, (2015). *Australia's Innovation Future: A Report on the Structure and Performance of Australia's National Innovation System*. https://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Economics/Innovation_System/~/media/Committees/economics_ctte/Innovation_System/Final_Report/e05.pdf

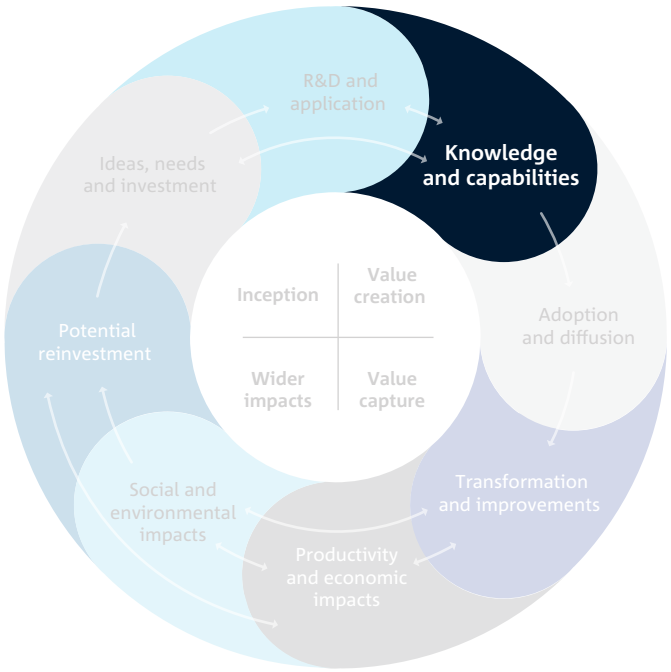
117 Ford, J.A., & Brea, E. (2020). *Thriving Through Innovation: Lessons From the Top*. CSIRO, Australia

118 Industry Innovation and Science Australia. (2020). *Stimulating business investment in innovation*. https://www.industry.gov.au/data-and-publications/stimulating-business-investment-in-innovation

119 DIIS, Office of the Chief Economist. (2016). *Australian Innovation System Report*. Office of the Chief Economist, Australian Department of Industry, Innovation and Science.

120 Industry Innovation and Science Australia. (2019). *Australia 2030: Prosperity through Innovation*. https://www.industry.gov.au/data-and-publications/australia-2030-prosperity-through-innovation; DIIS. (2018). *Australian Government response to Innovation and Science Australia's Australia 2030: Prosperity through Innovation.* https://www.industry.gov.au/sites/default/files/government-response-isa-2030-plan.pdf?acsf_files_redirect

2.3 Skills, knowledge and capability



2.3.1 Challenge: Gaps in skills, knowledge and capabilities

The quality of Australian tertiary education is very high by international standards, ranking 5th globally by the GII in 2020.[121] However, there are concerning skills mismatches and shortages in areas relevant to innovation, including technology management, process design, computer science and specialist STEM skills. As one consultation stakeholder described the challenge, "we [Australia] have gaps in people's ability to connect, convene and catalyse." Over a quarter of Australia's workforce is over-qualified or under-qualified,[122] and Australia ranked highly among OECD countries for in-country skill mismatches in 2016.[123] 20% of Australian businesses believe a lack of skilled talent is their major barrier to innovation.[124] At the leadership level, there is a shortage of Australian technologists and senior management with skills to lead through technological transformations and novel innovations, especially new-to-world, driven in part by a 'brain drain' of young talent.[125] This shortage extends to Australian boardrooms, which lack critical technical and innovation skills and access to specialist advice.[126] In short, Australian businesses need more workers with innovation-related skills to narrow the gap between skill demand and supply.[127] Figure 7 illustrates how skills shortages are present in all businesses but are especially pronounced in innovation-active businesses.

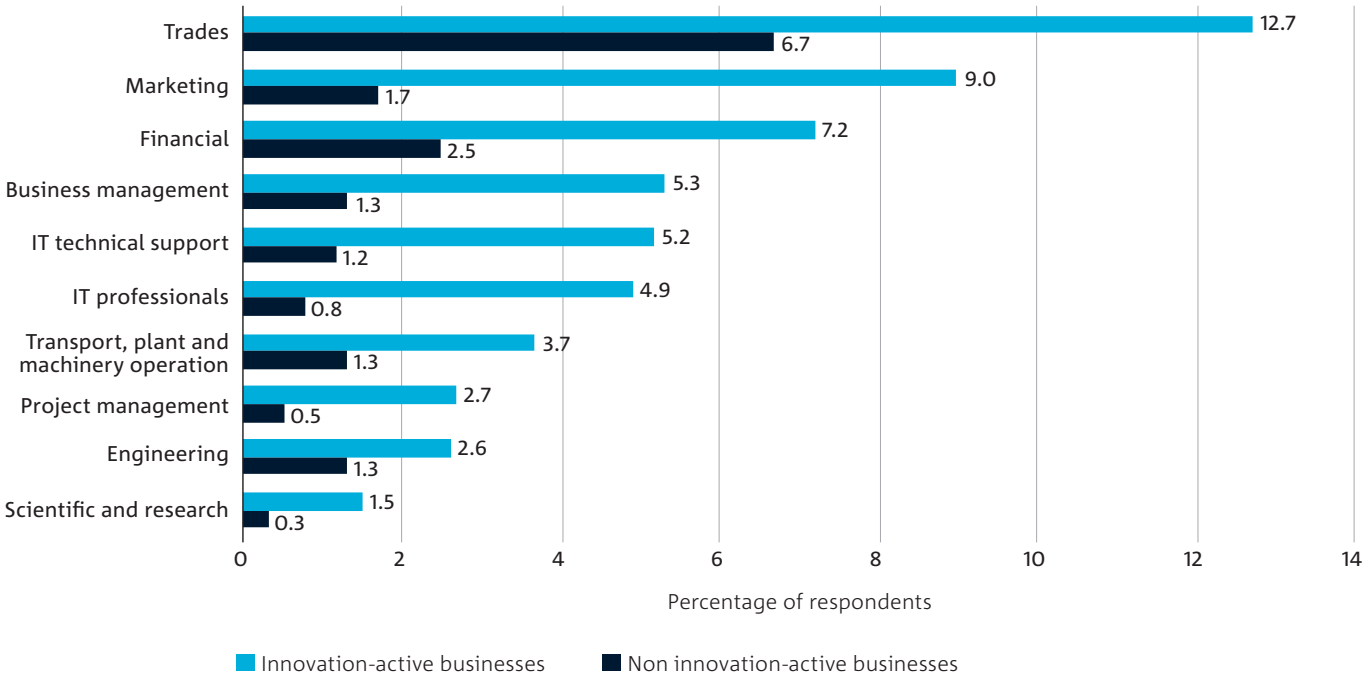


Figure 7: Skills shortages or deficiencies reported by all businesses, by skill type, by innovation status, 2014-15

Source: Australian Department of Industry, Innovation and Science (DIIS), Office of the Chief Economist. (2016). Australian Innovation System Report, Office of the Chief Economist. Australian Department of Industry, Innovation and Science

121 Global Innovation Index. (2020). *Australia – Economy analysis*. https://www.globalinnovationindex.org/analysis-economy

122 CSIRO. (2019). *Australia National Outlook*.

123 OECD. (2020). Mismatch, https://stats.oecd.org/Index.aspx?DataSetCode=MISMATCH

124 Office of the Chief Economist. (2018). Ibid

125 Monash University. (2017). *How Do We Fix Stem's Brain Drain?* https://www2.monash.edu/impact/articles/economy/how-do-we-fix-stems-brain-drain/

126 AICD. (2019). *Driving innovation: the boardroom gap.* https://aicd.companydirectors.com.au/advocacy/research/driving-innovation-the-boardroom-gap, Australian Institute for Company Directors

127 Industry Innovation and Science Australia. (2016). *Performance Review of the Australian Innovation*. Science and Research System.

There is a complex web of causes for innovation skill mismatches. Within industry, key issues include:

1. As technology and automation become ubiquitous, and continue to disrupt business and employment models, **skills-to-work pathways have become increasingly complex**. Individuals find it difficult to find information to make informed decisions about what to learn.[128] 70% of young people currently enter the workforce in jobs that will be radically affected by automation.[129] By 2022, an estimated 54% of all employees will require significant re- and up-skilling, and analytical thinking and innovation skills requirements will grow in prominence.[130] The increasing rate of change is a challenge for education providers, as is the consultation process of keeping up to date with industry needs.[131] While government remains the primary funder and regulator of VET programs, alternative sources of funding, such as industry bodies, are expected to become increasingly important. A scenario study has shown that under a business-as-usual scenario, funding will become increasingly strained and the skills and training sectors will increasingly look to profitable sectors to share the costs of upskilling.[132] In terms of responsibilities, 54% of Australian CEOs see it as their responsibility to retain employees who are displaced by automation (compared to a global average of 67%), while 74% of employees think upskilling is their responsibility.[133] Research shows that business investment in re-skilling the workforce is a more efficient pathway than individual undertakings.[134]
2. **Poor knowledge absorption** by Australian businesses is another major barrier for innovation, and one that limits Australia's national capabilities. 'Absorptive capacity'[135] is the ability to recognise the value of information, and apply it effectively, allowing workers to better learn the required skills to respond with agility to emerging opportunities.[136] Absorptive capacity, driven in part by knowledge assets, is a primary driver of innovation and is highly correlated with the ability to generate ideas internally.[137] Businesses with a high capacity to absorb external knowledge can more easily adopt and adapt new ideas, and eventually create knowledge assets which can be exported.[138] Conversely, businesses that lack staff with the skills and other resources to identify and absorb new knowledge are typically unable to develop knowledge assets. This ultimately reduces their ability to create new or adopted innovation.[139] The GII ranked Australia very poorly at 47th globally for knowledge absorption; measured by intellectual property payments, high-tech and ICT imports, FDI inflows and research talent.[140] Australia is also a net importer of knowledge assets, while most OECD countries – and certainly the innovation leaders – are net exporters of knowledge assets.[141]

Skills shortages and mismatches limit businesses' ability to identify, use and build knowledge assets, and restricts the innovation cycle. Without enough of the right foundational skills and knowledge, Australia's workforce cannot sufficiently develop and apply the capabilities needed to realise value from innovation.

128 Business Council of Australia. (2018). *Future-proof: Australia's future post-secondary education and skills system.* https://d3n8a8pro7vhmx.cloudfront.net/bca/pages/4386/attachments/original/1542258016/LoRes-2018_BCA_EDUC_Future_Proof_WIP1A_%281%29.pdf?1542258016

129 Reeson, A., Mason C., Sanderson, T., Bratanova, A. & Hajkowicz, S. (2016). *The VET Era: Equipping Australia's workforce for the future digital economy*. CSIRO, Data 61 report for TAFE Queensland

130 World Economic Forum. (2018). The Future of Jobs Report 2018. Centre for the New Economy and Society, Insight Report. http://www3.weforum.org/docs/WEF_Future_of_Jobs_2018.pdf

131 Reeson, A., Mason C., Sanderson, T., Bratanova, A. & Hajkowicz, S. (2016). *The VET Era: Equipping Australia's workforce for the future digital economy*. CSIRO, Data 61 report for TAFE Queensland.

132 Australian Industry and Skills Committee. (2017). *Future skills and training: A practical resource to help identify future skills and training.* https://www.aisc.net.au/sites/default/files/documents/Future%20Priority%20Skills%20Resource.pdf

133 PwC. (2018). Report: CEO Survey – the opportunity in the skills shortage. *Digital Pulse*. https://www.digitalpulse.pwc.com.au/report-pwc-ceo-survey-skills-shortage/

134 PwC. (n.d.) *Workforce of the Future: The competing forces shaping 2030*. https://www.pwc.com/gx/en/services/people-organisation/publications/workforce-of-the-future.html/?utm_source=digitalpulse&utm_campaign=digitalpulse&utm_medium=referral

135 Rassenfosse & Webster (2016) define absorptive capacity as a summary measure of a firm's ability to recognize the value of external information, assimilate it, and apply it to useful ends, such as profits. Source: Rassenfosse, G. & Webster, E. (2016). *An Assessment of Australia's Absorptive Capacity.* Melbourne Institute of Applied Economic and Social Research, and Intellectual Property Research Institute of Australia, The University of Melbourne, https://www.swinburne.edu.au/media/swinburneeduau/research/research-centres/cti/reports/rassenfoss-webster-assessment-of-australia's-absorptive-capacity-2016.pdf

136 Grandinetti, R. (2016). *Absorptive capacity and knowledge management in small and medium enterprises*; Rassenfosse, G. & Webster, E. (2016). Ibid.

137 Knowledge assets refers to valuable product, process or organisational knowledge skills, as differentiated from managerial and professional skills. Knowledge assets are more broadly understood as the accumulated intellectual resources of organisations. The stock of knowledge assets is generally regarded as a determinant of absorptive capacity. Source: Rassenfosse, G. & Webster, E. (2016). *An Assessment of Australia's Absorptive Capacity*. Melbourne Institute of Applied Economic and Social Research, and Intellectual Property Research Institute of Australia, The University of Melbourne, https://www.swinburne.edu.au/media/swinburneeduau/research/research-centres/cti/reports/rassenfoss-webster-assessment-of-australia's-absorptive-capacity-2016.pdf

138 DIIS, Office of the Chief Economist. (2016). *Australian Innovation System Report.* Office of the Chief Economist, Australian Department of Industry, Innovation and Science; Industry Innovation and Science Australia (2016). *Performance Review of the Australian Innovation, Science and Research System*. https://www.industry.gov.au/sites/default/files/2018-10/performance-review-of-the-australian-innovation-science-and-research-system-isa.pdf

139 Knowledge assets refers to valuable product, process or organisational knowledge skills, as differentiated from managerial and professional skills. Knowledge assets are more broadly.

140 Global Innovation Index. (2020). *Australia – Economy analysis*. https://www.globalinnovationindex.org/analysis-economy

141 Global Innovation Index. (2020). *Australia – Economy analysis*. https://www.globalinnovationindex.org/analysis-economy

2.3.2 Opportunity: Target gaps in knowledge capability, and skills

Australian businesses can improve their knowledge and capabilities and fill skill gaps through broader access to education and training, adapted teaching methods for innovative problem-solving, alignment of skills closer to industry needs, and deeper innovation management capabilities.

Emphasising fit-for-purpose skills and work-based continuous learning

An increased emphasis on and participation in interdisciplinary programs at the intersection of computer science, technology, engineering, marketing, process design, management and creative industries, will better prepare Australia's future workforce for work-based continuous learning within future innovative industries.[142] The top general skills used by innovation-active businesses are financial and marketing skills, alongside more specific innovation skills including venture capital and legal skills.[143] By focusing on developing skills relevant to future challenges and innovative solutions, students and workers are likely to become more purposeful, engaged, productive and capable of building closer relationships.[144] Many studies also show strong linkages between improved innovation-related skills and businesses' economic performance.[145]

Through collaboration with the education sector and government, businesses can also ensure that Australia's training systems deliver a talent pool suited to their innovation objectives. There are many ways in which businesses can achieve this, including by:

- enhancing engagement in public-private partnerships and industry consortia
- setting their own skills development strategy and collaborating with government to shape curriculums and the delivery of education and training
- directly delivering training programs outside of traditional pathways, for example, using co-created or open online education platforms and work trial programmes.[146]

As businesses prepare to ramp up innovative business models after COVID-19, strategic workforce planning will be key. Businesses that launch successful reskilling programmes are better able to address skills gaps, and even businesses that 'fail fast' at their reskilling programs are prepared to iterate their approach and take on future skills gaps.[147] Although industry-education collaboration is already occurring, more can be done to build high-quality, two-way communication between skills providers and employers to support workforce planning and responsiveness to a fast-changing environment.[148]

142 Green, R., & Howard, J. H, (2015). *Australia's Innovation Future: A Report on the Structure and Performance of Australia's National Innovation System.* https://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Economics/Innovation_System/~/media/Committees/economics_ctte/Innovation_System/Final_Report/e05.pdf; Senate Economics Reference Committee. (2015). Senate inquiry report, December 2015. https://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Economics/Innovation_System/Report; OECD. (2016). *Strengthening education and skills for innovation*. https://www.oecd-ilibrary.org/science-and-technology/oecd-science-technology-and-innovation-outlook-2016/strengthening-education-and-skills-for-innovation_sti_in_outlook-2016-40-en; OECD. (2018). *OECD Science, Technology and Innovation Outlook 2018*. https://www.oecd.org/sti/oecd-science-technology-and-innovation-outlook-25186167.htm

143 Industry Innovation and Science Australia. (2016). *Performance Review of the Australian Innovation, Science and Research System*. Industry Innovation and Science Australia

144 OECD. (2017). *Better Use of Skills in the Workplace*. https://www.oecd-ilibrary.org/docserver/9789264281394-en.pdf?expires=1582603380&id=id&accname=ocid177482a&checksum=0F15E4357EFEDC98ED338ACD4DC639EF; Industry Innovation and Science Australia. (2019). *Australia 2030: Prosperity through Innovation*. https://www.industry.gov.au/data-and-publications/australia-2030-prosperity-through-innovation; DIIS. (2018) *Australian Government response to Innovation and Science Australia's Australia 2030: Prosperity through Innovation*. https://www.industry.gov.au/sites/default/files/government-response-isa-2030-plan.pdf?acsf_files_redirect

145 See for instance: Schneider, L., Günther, J., & Brandenburg, B. (2010). Innovation and skills from a sectoral perspective: a linked employer–employee analysis. *Economics of Innovation and New Technology*, 19(2), 185-202.; Leiponen, A. (2000). Competencies, innovation and profitability of firms. *Economics of innovation and new technology*, 9(1), 1-24.

146 Australian Industry and Skills Committee. (2017). *Future skills and training: A practical resource to help identify future skills and training.* https://www.aisc.net.au/sites/default/files/documents/Future%20Priority%20Skills%20Resource.pdf

147 Agrawal, S., De Smet, A., Lacroix, S & Reich, A. (2020). *To emerge stronger from the COVID-19 crisis, companies should start reskilling their workforces now*. McKinsey & Company.

148 Reeson, A., Mason C., Sanderson, T., Bratanova, A. & Hajkowicz, S. (2016). *The VET Era: Equipping Australia's workforce for the future digital economy*. CSIRO, Data 61 report for TAFE Queensland

Support innovation management skills and information sharing

There is significant evidence of the impact of management practices on business performance, and on the role of innovation activeness and information sharing in driving this relationship. [149] The effectiveness of management practices explains roughly half of the total factor productivity gap between the United States and Australia.[150] Businesses can facilitate access to innovation-related management skills, through training and other opportunities for skills development and advice such as the Australian Government's Entrepreneurs' Programme.[151] Investing in effective systems of knowledge creation and diffusion will allow organisations to improve their absorptive capacity, making workforces better able to learn new skills.[152] Organisations can also accumulate and share knowledge about capability gaps across value chains, providing skills development training and adapting incentives as needed, to remove innovation barriers.[153] Here, capturing the value of data and wide-spread reliable access to digital infrastructure provides many opportunities for diagnosing issues and determining how to correct skills mismatches, to understand end-users and make incremental improvements that speed up innovation cycles.[154] Across sectors, Australian organisations can benefit immensely from building communities of practice around skills alignment, training and knowledge sharing. Businesses can also facilitate better information sharing, through training, cultural change that encourages sharing, and communities of practice.[155] Data shows that innovation-active businesses have a higher management capability,[156] and source their management practice knowledge from communities of practice (such as within their own businesses, professional networks and industry associations) at a higher rate than non-innovation active businesses.[157] Combining management skills with information sharing, businesses can also better use the data available to them to identify and correct skills mismatches, to understand end-users and make incremental improvements that speed up innovation cycles. [158]

Additional ways of accessing and retaining talent

In addition to creating on-the-job and learning opportunities, novel ways of addressing the skills gap includes new approaches to sourcing and retention, and new business models. Firstly, accessing untapped pools of talent internally and externally, requires improving internal transparency and communication to mobilise internal resources, and finding people in 'alternative' workforces. There are also new ways of assessing capability such as leveraging new technologies to augment sourcing of candidates by looking beyond qualifications to traits that are predictors of success.[159] Secondly, new business models for 'offshoring', 'inshoring' or hybridized models may be effective for acquiring talent externally, however, successful execution of these models relies on careful integration with business structures and leveraging of technologies.[160] Finally, retention is also critically important as scarce talent can be lost to competition. Offering flexibility over traditional work schemes, fostering 'intrapreneurship', and a clear sense of purpose can help businesses retain skills and manage competition risk.[161]

149 Office of the Chief Economist. (2018). *Industry Insights – Future Productivity.*

150 Office of the Chief Economist. (2018). *Industry Insights – Future Productivity*; Bloom, N., Sadun, R., and Van Reenen, R. (2016). Management as a Technology? *NBER Working Papers 22327*. National Bureau of Economic Research.

151 Australian Government. (2020). Entrepreneurs' Programme. https://www.business.gov.au/Grants-and-Programs/Entrepreneurs-Programme; Industry Innovation and Science Australia. (2020). *Stimulating business investment in innovation*. https://www.industry.gov.au/data-and-publications/stimulating-business-investment-in-innovation; DIIS. (2018). *Future productivity 03/2018*. Department of Industry, Innovation and Science (DIIS). https://publications.industry.gov.au/publications/industryinsightsjune2018/future-productivity.html; AICD. (2019). *Driving innovation: the boardroom gap*. https://aicd.companydirectors.com.au/advocacy/research/driving-innovation-the-boardroom-gap

152 OECD. (2015). *The innovation imperative.* https://www.oecd.org/publications/the-innovation-imperative-9789264239814-en.htm

153 OECD. (2011). *Skills for Innovation and Research*. https://www.oecd.org/sti/inno/skillsforinnovationandresearch.htm

154 OECD. (2018). *OECD Science, Technology and Innovation Outlook 2018*. https://www.oecd.org/sti/oecd-science-technology-and-innovation-outlook-25186167.htm; DIIS. (2019). Australian Innovation System Monitor. https://publications.industry.gov.au/publications/australianinnovationsystemmonitor/index.html

155 OECD. (2015). *The innovation imperative*. https://www.oecd.org/publications/the-innovation-imperative-9789264239814-en.htm; OECD. (2011). *Skills for Innovation and Research*, https://www.oecd.org/sti/inno/skillsforinnovationandresearch.htm

156 Agarwal R., Bajada, C., Brown, P., Moran, I. & Blaguer, B. (2019). *Development of Management Capability Scores*. DIIS, Office of the Chief Economist, EDAN.

157 ABS. (2017). 8172.0 – *Management and Organisational Capabilities of Australian Business, 2015-16*. https://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/8172.02015-16?OpenDocument

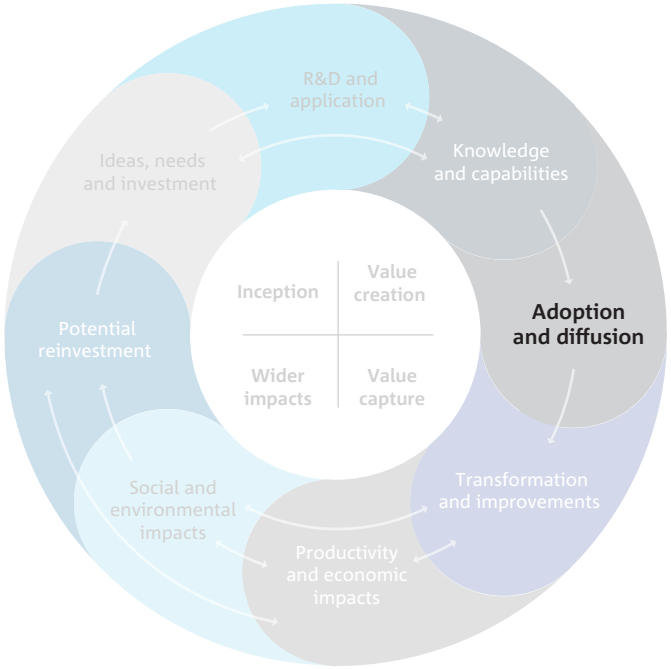
158 DIIS. (2019). *Australian Innovation System Monitor*. https://publications.industry.gov.au/publications/australianinnovationsystemmonitor/index.html; OECD (2018). *OECD Science, Technology and Innovation Outlook 2018*. https://www.oecd.org/sti/oecd-science-technology-and-innovation-outlook-25186167.htm

159 Deloitte. (2019) Accessing talent: It's more than just acquisition. *Deloitte Insights.* https://www2.deloitte.com/us/en/insights/focus/human-capital-trends/2019/talent-acquisition-trends-strategies.html

160 PwC. (2017). Why offshoring is no longer a dirty word. *Digital Pulse*. https://www.digitalpulse.pwc.com.au/digital-delivery-fresh-take-offshoring/

161 EY. (2018). *Three ways to attract and retain talent in the age of disruption*. https://www.ey.com/en_au/workforce/three-ways-to-attract-and-retain-talent-in-the-age-of-disruption

2.4 Adoption and diffusion



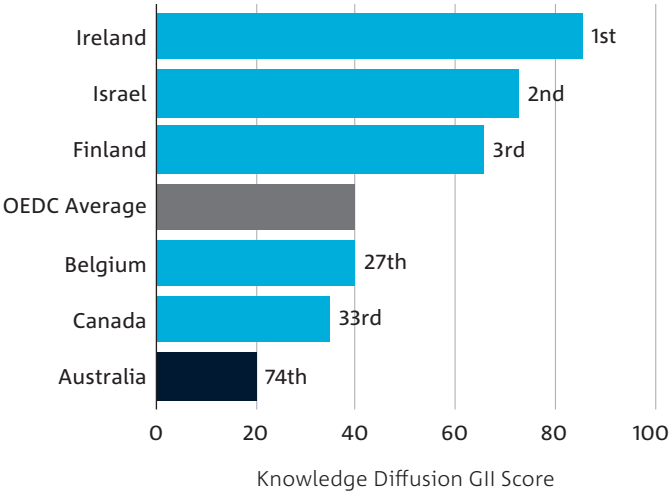


Figure 8: Knowledge Diffusion GII Score and Global Ranking

Source: Global Innovation Index. https://www.globalinnovationindex.org/analysis-indicator

2.4.1 Challenge: Poor adoption from overseas and poor diffusion

Although there are success stories of technologies being adopted and diffused across the Australian economy, they remain exceptions rather than the norm, indicating that Australia may be missing out on available innovation opportunities.

In a survey of Australian businesses, 9% of goods and services innovations in Australia were new to the world, and 9% were new to Australia (but not new to the world). The remaining goods and services innovations were adopted and diffused from innovations that already existed in the domestic market.[162] This indicates that most Australian businesses are not looking beyond the small domestic market for ways to improve and do things differently.

The impetus to adopt and diffuse new technologies is driven in part by attitudes including perceptions of risk regarding technological disruption and change. For instance, a Deloitte study found that only 22% of Australian executives likely to face disruption from AI were willing to develop and adopt AI, compared with 55% of executives in China, 47% in Germany and 44% in the United Kingdom.[163] These adoption trends and attitudes may reflect a lower capacity to generate innovations that could yield large economic impacts.[164]

To see the benefits of innovation across the economy, businesses must adopt technologies and diffuse accompanying knowledge into the economy. Yet Australia is poor at diffusion, ranking 74th for diffusion on the GII 2020 (shown in Figure 8); a significant weakness among peer advanced economies.[165] By restricting the spread of innovation, it becomes more difficult for Australian businesses to access technologies and knowledge, and use them to increase their productivity and competitiveness.[166] Low rates of diffusion also appear to drive a gap between frontier businesses (those with high productivity and high rates of innovation) and laggards (non-frontier businesses); contributing to unbalanced economic growth and innovation at the industry and national levels.[167] Divergences between frontier and laggard businesses are a common feature in advanced economies, revealing systemic tendencies towards self-perpetuating cycles of advantage and disadvantage. Across advanced economies since the start of the century, frontier businesses have enjoyed 3-4% annual productivity growth, compared with about 0.5% annually for laggards.[168]

162 Australian Bureau of Statistics. (2019). 8167.0 – *Characteristics of Australian Business, 2018-19*. https://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/8167.02018-19?OpenDocument

163 Deloitte. (2019). *Future in the Balance? How Countries are Pursuing an AI Advantage. Deloitte State of AI in the Enterprise Survey.* https://www2.deloitte.com/content/dam/insights/us/articles/5189_Global-AI-survey/DI_AI-Global-Survey-Synopsis.pdf

164 Industry Innovation and Science Australia. (2016). *Performance Review of the Australian Innovation, Science and Research System.*

165 Global Innovation Index. (2020). *Australia – Economy analysis*. https://www.globalinnovationindex.org/analysis-economy

166 Andrews, D., Criscuolo, C. & Gal, P. (2015). *Frontier Firms, Technology Diffusion and Public Policy: Micro Evidence from OECD Countries (The Future of Productivity: Main Background Papers)* OECD. http://www.oecd.org/economy/growth/Frontier-Firms-Technology-Diffusion-and-Public-Policy-Micro-Evidence-from-OECD-Countries.pdf

167 Andrews, D., Criscuolo, C. & Gal, P. (2015). *Frontier Firms, Technology Diffusion and Public Policy: Micro Evidence from OECD Countries. (The Future of Productivity: Main Background Papers)* OECD. http://www.oecd.org/economy/growth/Frontier-Firms-Technology-Diffusion-and-Public-Policy-Micro-Evidence-from-OECD-Countries.pdf. Unlike other countries however, this gap does not appear to be increasing over time in Australia: Andrews, D., Deutscher, N., Hambur, J. and Hansell, D. (2019). *Wage Growth in Australia: Lessons from Longitudinal Microdata*. https://treasury.gov.au/sites/default/files/2019-07/2019-04_wage_growth_in_australia_lessons_from_longitudinal_microdata.pdf.

168 Andrews, D., Criscuolo, C. & Gal, P. (2016). The Global Productivity Slowdown, Technology Divergence, and Public Policy: A Firm Level Perspective. *Hutchins Center Working Paper No. 24.* Brookings Institution; Gans, J., & Leigh, A. (2019). *Innovation+ Equality: How to Create a Future That Is More Star Trek Than Terminator*. MIT Press.

In Australia, adding low diffusion to the mix hinders what can already be a very slow process of realising the benefits of research, knowledge and S&T innovation.[169]

Poor adoption and diffusion are interlinked with several key challenges including insufficient non-R&D innovation; insufficient business-to-business collaboration; and ineffective clustering and networking of innovation activities.

1. Once innovations are available in the market, realising their value involves leveraging complementary non-R&D innovation.[170] Non-R&D innovation includes the development or adoption of software platforms that improve productivity, or business models that take advantage of digital technologies across all areas of business including finance, human resource management, marketing and sales. For SMEs that may not have the resources to perform R&D, non-R&D innovation is also a means of innovation in itself.[171] Australian businesses invest roughly equally in R&D and non-R&D.[172] Although business investment in non-R&D has been increasing, Australia still invests less than most developed economies.[173]

2. Aside from industry-research collaboration described in earlier challenges, Australia also performs poorly on business-to-business collaboration and international collaboration. Innovation-active businesses that collaborated for innovation have declined from 17% to 14% over the last decade.[174] Meanwhile, Australia ranks below the OECD average for participation in global value chains low levels.[175] This lack of collaboration makes it harder to adopt and diffuse innovations.

3. Organisations located within innovation clusters are more likely to engage in collaborative activities, adopt new technologies, attract financing for innovation, and share knowledge within their clusters. This holds especially true when these clusters are networked across a broader system to share innovations, whether geographically co-located or connected via virtual means.[176] Resources, opportunities and ideas tend to be concentrated in areas of high potential growth, where 'agglomeration effects'[177] increase the competitiveness of co-located organisations.[178] Although some Australian industries are well-clustered to share knowledge, such as the R&D corporation network in agriculture,[179] developing effective innovation clusters remains a challenge for most Australian industries. A study of 19 industries across 8 Australian capital cities found Australia has relatively low levels of beneficial agglomeration effects.[180] Australia's geographical isolation and relative economic prosperity over the past few decades (creating a lack of a sense of urgency to change) are possible causes for low levels of clustering.[181]

Difficulties in collaborating for innovation, developing effective clusters, accessing global value chains and capturing the economic benefits of agglomeration can result in lower rates of productivity, economic growth and sharing of resources.[182]

169 OECD. (2015). *The Innovation Imperative: Contributing to Productivity, Growth and Well-Being*. https://www.oecd.org/site/innovationstrategy/

170 Examples of non-R&D innovation include "investing in the development or adoption of software platforms that improve business productivity, or the reinvention of entire business models to take advantage of digital technologies". Source: Industry Innovation and Science Australia. (2020). *Stimulating business investment in innovation*. https://www.industry.gov.au/data-and-publications/stimulating-business-investment-in-innovation

171 Industry Innovation and Science Australia. (2020). *Stimulating Business Investment in Innovation*. https://www.industry.gov.au/data-and-publications/stimulating-business-investment-in-innovation

172 Industry Innovation and Science Australia. (2020). *Stimulating Business Investment in Innovation*. https://www.industry.gov.au/data-and-publications/stimulating-business-investment-in-innovation.

173 AlphaBeta. (2019). *Australian business investment in innovation: levels trends, and drivers.* https://www.industry.gov.au/sites/default/files/2020-02/australian-business-investment-in-innovation-levels-trends-and-drivers.pdf

174 Australian Bureau of Statistics (2010). *Innovation in Australian Business, 2008-09*. https://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/8158.02008-09?OpenDocument; Australian Bureau of Statistics. (2020). *Characteristics of Australian Businesses, 2018-19*. https://www.abs.gov.au/statistics/industry/technology-and-innovation/characteristics-australian-business/latest-release#data-download

175 Austrade. (2016). *Australia's participation in Global Value Chains*. http://www.austrade.gov.au/news/economic-analysis/australia-s-participation-in-globalvalue-chains

176 Banerjee, A. & Duflo, E. (2019). *Good Economics for Hard Times*. PublicAffairs; Belussi, F., & Caldari, K. (2009). At the origin of the industrial district: Alfred Marshall and the Cambridge school. *Cambridge Journal of economics*, 33(2), 335-355; Gross, D. & Sampat, B. (2020). Inventing the endless frontier: The effects of the World War II research effort on post-war innovation. NBER Working Paper 27375. http://www.nber.org/papers/w273735.

177 Agglomeration' refers to the concentration of people and industry within a region. Agglomeration effects refers to cost savings that arise when firms are located near to each other, typically in urban centres. This also arises due to economies of scale and network effects, where increased density of activity and employment reduces the cost per unit of output whilst increasing revenues as more customers or clients use the products or services provided. Ultimately clustering can accelerate development and growth. Source: Thisse, J. F. (2019). Economics of agglomeration. In *Oxford Research Encyclopedia of Economics and Finance*.

178 Mazzucato, M. (2015). *The Entrepreneurial State (US Edition).* New York: PublicAffairs.

179 Rural R&D Corporations. (2018). *Innovation through collaboration*. http://www.ruralrdc.com.au/case-studies/innovation-through-collaboration/

180 Australian Bureau of Statistics. (2017). *Estimating Agglomerations Elasticities for Wider Economic Benefits of Transport Projects*. https://www.abs.gov.au/AUSSTATS/abs@.nsf/Previousproducts/1504.0Main%20Features3Dec%202017?opendocument&tabname=Summary&prodno=1504.0&issue=Dec%202017&num=&view=; KPMG (2017). *Measuring WEBS in Australian Cities* (prepared for Australian Bureau of industry, Transport and Regional Economics).

181 Industry Innovation and Science Australia. (2016). *Performance Review of the Australian Innovation, Science and Research System*. https://www.industry.gov.au/sites/default/files/2018-10/performance-review-of-the-australian-innovation-science-and-research-system-isa.pdf

182 Kolehmainen, J. (2002). Territorial agglomeration as a local innovation environment the case of a digital media agglomeration in Tampere, Finland. *Massachusetts Institute of Technology, Special working paper series on local innovation systems*, 25, 29.

2.4.2 Opportunity: Improve adoption and diffusion

Adopting more S&T innovations from overseas and diffusing via continuous, incremental improvements and non-R&D innovation can help capture greater benefits from innovation. At the economy-wide level, Australia can further develop its innovation clusters and industry growth centres to increase productivity, reduce costs and promote knowledge sharing.

Adoption and non-R&D innovation opportunities

Australian businesses can better adopt technologies and diffuse innovation by employing an incremental approach to innovation and drawing on 'non-R&D' innovation. Businesses can take several complementary strategies at once: adopt more innovations from overseas and across industries; improve product and process quality at the margins by 'tinkering'; and keep track of new S&T innovation opportunities to remain innovation-ready.[183] Non-R&D innovation complements R&D innovation at the organisational level, which creates significant public value and economy-wide benefits. Incremental improvements to organisational processes and operational models provide accessible ways to continuously innovate and increase profitability for organisations for which R&D innovation may not be suitable.[184] For instance, roughly 95% of innovation-driven productivity arises from improvements in information diffusion, data integration and building supply chain connections.[185] Non-R&D improvements also include, for instance, marketing Australian products as high-quality, 'clean and green' to increase foreign demand, notably from China.[186]

Develop innovation clusters and growth industries

Clusters of innovative activity, where spillovers and economies of scale naturally occur, can accelerate virtuous cycles between innovation and agglomeration effects. Industry clustering and precincts are important to achieving smart specialisation in global markets and value chains, and key to achieving competitive advantage.[187] Organisations located in innovation clusters are more likely to collaborate, adopt new technologies, share knowledge, attract investment and talent.[188] Whether these organisations are co-located geographically or connected virtually, effective clustering can increase competitiveness and profitability.[189] Building densely networked clusters around industries of high innovation-led growth potential can accelerate the cross-sector collaboration, targeted development and innovation diffusion that Australian businesses need for a resilient, productive future.

183 AlphaBeta. (2020). *Australian Business Investment in Innovation*. https://www.AlphaBeta.com/our-research/improving-australias-innovation-performance

184 This analysis using BLADE shows that the frequency of innovation matters, as the positive impact of innovation gets stronger when businesses innovate more frequently. DIIS, Office of the Chief Economist (2016). Australian Innovation System Report, Office of the Chief Economist, Australian Department of Industry, Innovation and Science

185 Australian Bureau of Statistics. (2019). Business Longitudinal Analysis Data Environment (BLADE) Research Projects, https://www.abs.gov.au/websitedbs/D3310114.nsf/home/Statistical+Data+Integration+-+BLADE+Research+Projects; Green, R., & Howard, J. H. (2015). *Australia's Innovation Future: A Report on the Structure and Performance of Australia's National Innovation System*. www.aph.gov.au/Parliamentary_Business/Committees/Senate/Economics/Innovation_System/~/media/Committees/economics_ctte/Innovation_System/Final_Report/e05. pdf

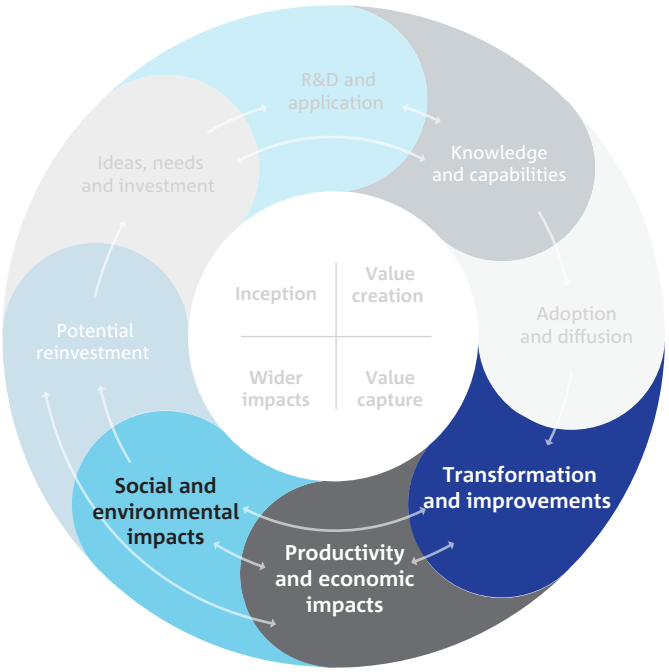
186 Austrade. (2020). *Consumer products to China (personal care, fashion): Trends and opportunities*. https://www.austrade.gov.au/australian/export/export-markets/countries/china/industries/Consumer-products

187 InnovationAus. (2020). Roy Green on a new manufacturing regime. *InnovationAus.* https://www.innovationaus.com/roy-green-on-a-new-manufacturing-regime/

188 Banerjee, A. & Duflo, E. (2019). *Good Economics for Hard Times*. PublicAffairs.

189 Banerjee, A. & Duflo, E. (2019). *Good Economics for Hard Times*. PublicAffairs.

2.5 Social and environmental impacts



2.5.1 Challenge: Maximizing the benefits and mitigating the costs of innovation for society and environment

Despite the outlined benefits of innovation and technology for the economy, society and environment, there are also social and environmental costs. Society and environment are often not the initial motivation for innovation. As such, innovators may not maximize the benefits, and innovation activity may result in known or unintended negative impacts. Actual and perceived costs can also hinder Australia's innovation activities and reduce or even negate the positive impacts of innovation. Corporate social responsibility requires consideration of all three aspects, economic, social and environmental, and is critical to creating and maintaining businesses' social licence to operate.

Social costs of innovation

The social considerations of innovation include the costs and benefits of innovation on industry itself, its stakeholders and the public. Many (but not all) of these costs are inequity concerns around the impacts of technology:

- **Threats of job displacement for low-skilled jobs:** Studies have proposed a range of effects of automation on job numbers for Australia, the world and other specific countries, with some studies predicting an increase in jobs (of up to approximately 20%), some predicting a net-zero effect on jobs and others predicting a decrease in jobs (of up to approximately 50%).[190] Although the net effect of automation on job numbers is uncertain, threats of job displacement, particularly for low-skill jobs, is perceived negatively by parts of society.

- **The dominance of oligopolistic technology businesses and the uneven distribution of value between large businesses and SMEs:** Technology is the largest sector globally, and technology businesses represent both the top two global businesses and five of the top 10 global businesses (by market capitalisation).[191] Many SMEs do not see the same benefits in terms of competitive advantage and profitability as do large businesses in Australia. Large businesses enjoy consistently higher revenue and reduced costs from economies of scale, and higher market shares and profits, and a greater competitive edge from innovation compared to SMEs.[192] These differences suggest that innovation could intensify the competitive advantage of large businesses and thereby concentrate wealth in pockets of the economy.[193] Furthermore, a sense of inequity naturally arises as people witness wealth accumulating within the technology sector,[194] while feeling that they are not receiving a fair share of the prosperity created by technological innovation.[195]

- **The value captured between the original inventor or investor and the party that eventually commercialises the innovation is often unevenly distributed:** Spillovers, long lag times and poor use of IP rules can often mean that the original inventor enjoys minimal or no commercial benefit from the commercialised innovation, as most of the value is captured by the party that sells the final product or service to the end-user. The public sector makes up much of early-stage innovation investment, and the private sector makes up much of later stage investment. This uneven distribution of value capture tends to negatively impact the public sector more than the private sector.[196]

190 For a summary of predictions of the effects of automation on jobs refer to CSIRO. (2019). Australian National Outlook 2019, p.9.

191 PwC. (2019). *Global Top 100 Companies*. https://www.pwc.com/gx/en/audit-services/publications/assets/global-top-100-companies-2019.pdf

192 About 61% of businesses over 20 people are innovation-active compared to 42.3% for businesses of 0–19 persons. Source: Australian Bureau of Statistics (2020). 8167.0 – Characteristics of Australian Business, 2018-19; Australian Bureau of Statistics. (2018). Table 1 Benefits of introduced innovation, by employment size, by industry – 2016-17, 81580DO010_201617 Innovation in Australian Business, 2016-17 [Latest release], https://www.abs.gov.au/ausstats/abs@.nsf/mf/8158.0

193 Porter, M. E. (2008). The five competitive forces that shape strategy. *Harvard Business Review*, 86(1), 25-40.

194 For instance, four of the five biggest multinational technology businesses - Alphabet, Amazon, Apple and Microsoft - are each now worth over $1trn. Source: The Economist (2020). *How to make sense of the latest tech surge*. https://www.economist.com/leaders/2020/02/20/how-to-make-sense-of-the-latest-tech-surge

195 Bell, S., & Keating, M. (2018). *Fair Share: Competing Claims and Australia's Economic Future*. Melbourne University Publishing.

196 Mazzucato, M. (2015). *The Entrepreneurial State (US Edition)*. New York: PublicAffairs.

- **Continued issues in digital inclusion, particularly in access to broadband services for people with low socioeconomic status or in rural areas, restricting the diffusion of digital technologies**: Australians with low levels of income, education, and employment are significantly less digitally included. People residing in rural Australia also continue to record lower levels of digital inclusion than those in capital cities. However, the gap between these groups has narrowed slightly in the last few years, in part due to the NBN rollout prioritising rural Australia.[197]

- **Ethics and privacy issues,** including discriminative algorithms[198] and 'surveillance capitalism', a process where businesses that provide free online services, such as search engines and social media platforms, collect and scrutinise online behaviours to produce data that can be sold and used to market products and services.[199]

- **Erosion of community trust in information:** Digital media and the manipulation of politics has eroded trust in private and public institutions. Examples include harvesting consumers personal data to assist political campaigning and the use of AI and machine learning in the production of deepfakes.[200] Fake news is also a concern for 62% of Australian news consumers, above the global average of 55%, [201] and there have been several Australian parliamentary inquiries and an inquiry by the Australian Competition and Consumer Commission examining issues related to fake news.[202]

- **Fear and/or allegations of national security threats and cyberattacks leading to protectionism and concerns around national sovereignty, data usage and storage:** National security is now considered closely linked to cybersecurity, and the global expansion of the internet and data flows is both transforming international trade and increasing Australia's exposure to cyber-attacks.[203] According to the Productivity Commission, "increases in inequality primarily reflect other disruptions, notably technological innovations; trade is invariably the scapegoat."[204] *Australia's 2020 Cybersecurity Strategy* discussion paper describes the rapid change in cyberspace and Australia's significant reliance on the internet and warns "a loss of an essential service like electricity, water or transport has the potential to cripple the economy, cause social unrest and, ultimately, damage our welfare and way of life."[205]

Despite these actual and perceived social concerns with innovation, technology adoption has historically supported incomes and shared prosperity in Australia,[206] with sustained economic growth lifting living standards across all income brackets.[207] The official measure of income inequality, the GINI coefficient, has only risen very slightly in Australia since 2011-12.[208] Taken from an international perspective, Australia sits roughly in the middle of its economic peers on income inequality.[209] Beyond this, it is exceedingly difficult to trace connections between innovation and social prosperity, due to the complex nature of economic and social systems. Nonetheless, there are frustrations among disadvantaged social groups in Australia that can be better addressed. Actual and perceived costs of innovation can impede potential innovators and make it difficult for innovators to secure support for and adoption of their innovations across the innovation cycle.

197 Roy Morgan, Telstra, Centre for Social Impact, Swinburne University of Technology, RMIT University. (2019). *Measuring Australia's Digital Divide: The Australian Digital Inclusion Index 2019.* https://www.csi.edu.au/media/2019_ADII_Report.pdf

198 Broussard, M. (2018). *Artificial Unintelligence: How Computers Misunderstand the World*. MIT Press.

199 Zuboff, S. (2019). *The Age of Surveillance Capitalism: The fight for a human future at the new frontier of power*. PublicAffairs; Holloway, D. (2019). Explainer: what is surveillance capitalism and how does it shape our economy? *The Conversation*. https://theconversation.com/explainer-what-is-surveillance-capitalism-and-how-does-it-shape-our-economy-119158

200 Cadwaladr, C. (2020) Fresh Cambridge Analytica leak 'shows global manipulation is out of control'. *The Guardian.* https://www.theguardian.com/uk-news/2020/jan/04/cambridge-analytica-data-leak-global-election-manipulation; Sample, I. (2020). What are deepfakes – and how can you spot them? *The Guardian*. https://www.theguardian.com/technology/2020/jan/13/what-are-deepfakes-and-how-can-you-spot-them

201 News and Media Research Centre. (2019). *Digital News Report: Australia 2019.* https://apo.org.au/sites/default/files/resource-files/2019-06/apo-nid240786.pdf.

202 Buckmaster, L. & Wils, T. (2019). Responding to fake news. *Parliamentary Library Briefing Book: Key issues for the 46th Parliament*. https://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/pubs/BriefingBook46p/FakeNews; ACCC. (2018). *Digital Platforms Inequity Preliminary Report.* https://www.accc.gov.au/system/files/ACCC%20Digital%20Platforms%20Inquiry%20-%20Preliminary%20Report.pdf; Wilding, D., Fray, P., Molitorisz, S. & McKewon, E. (2018). *The Impact of Digital Platforms on News and Journalistic Content*. University of Technology Sydney, NSW. https://www.accc.gov.au/system/files/ACCC%20commissioned%20report%20-%20The%20impact%20of%20digital%20platforms%20on%20news%20and%20journalistic%20content%2C%20Centre%20for%20Media%20Transition%20%282%29.pdf

203 Meltzer, J. (2019). Cybersecurity and digital trade: What role for international trade rules? *Working Paper #132, Global Economic and Development, Brookings Institution*. https://www.brookings.edu/wp-content/uploads/2019/11/Cybersecurity-and-digital-trade_-What-role-for-international-trade-rules.pdf

204 Productivity Commission. (2017). *Rising protectionism: challenges, threats and opportunities for Australia*. Canberra. https://www.pc.gov.au/research/completed/rising-protectionism

205 Australian Government. (2019). *Australia's 2020 Cyber Security Strategy: A call for views*. https://www.homeaffairs.gov.au/reports-and-pubs/files/cyber-security-strategy-2020-discussion-paper.pdf

206 McKinsey. (2019*). Australia's automation opportunity: Reigniting productivity and inclusive income growth.* https://www.mckinsey.com/~/media/McKinsey/Featured%20Insights/Future%20of%20Organizations/Australias%20automation%20opportunity%20Reigniting%20productivity%20and%20inclusive%20income%20growth/Australia-automation-opportunity-vF.ashx

207 Productivity Commission. (2018). *Rising inequality? A stocktake of the evidence*. Australian Government. https://www.pc.gov.au/research/completed/rising-inequality

208 Australian Bureau of Statistics. (2019). *ABS Survey of Income and Housing, 2017–18.* https://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/6523.0Main+Features62017-18?OpenDocument

209 Australia's GINI coefficient was 0.33 on average between 2015-19, compared with 0.29 for Germany and France, 0.31 for Canada, 0.35 for Korea and 0.36 for United Kingdom. Among the OECD, South Africa was the highest with 0.62 and Slovak Republic the lowest with 0.24 over this time period. Source: OECD. (2018). Income inequality, https://data.oecd.org/inequality/income-inequality.htm

Environmental costs of innovation

Innovation can increase or decrease pressure on the environment, but this depends on its direction. As the environment and its protection is often not the initial motivator for innovation, environmental impacts are often not considered by innovators or may even be negative. Furthermore, market failures such as under-priced externalities put pressure on the environment in two main ways. Firstly, the environment provides essential resources as inputs for production in many sectors. Secondly, the environment acts as a sink for emissions and waste generated from increased production and consumption.

Long-term economic growth and social well-being are dependent on a healthy environment and the availability of natural resources.[210] This is especially the case for Australia, where natural assets and a 'clean and green' reputation have historically supported the tourism and agricultural sectors and high 'most liveable' city rankings.[211] Even at the business level, avoiding environmental crises means reducing the risk of business disruption[212] and strengthening businesses' social licence to operate.

Total public and private R&D for environmental objectives has decreased by an average of approximately 5% per year, while total public and private R&D decreased on average 1% between 2012 and 2018 approximately, representing a decreasing share of funding towards environmental objectives over time.[213]

Despite businesses having tools to influence more sustainable innovation,[214] barriers continue to weaken private investment in environmental innovation, including a disconnect between investors seeking projects and project managers seeking funding, system and market failures, information gaps, undervaluation of natural capital, and reliance on voluntary commitments.[215]

210 Strange, T. & Bayley A. (2008). Sustainable Development: Linking economy, society and environment. *OECD Insights.* OECD.

211 The Economist Intelligence Unit. (2019). *Global Liveability Index 2019*. https://www.eiu.com/n/the-global-liveability-index-2019/

212 UNEP Finance Initiative. (2019). *Changing Course: A comprehensive investor guide to scenario-based methods for climate risk assessment, in response to the TCFD.* https://www.unepfi.org/wordpress/wp-content/uploads/2019/05/TCFD-Changing-Course-Oct-19.pdf

213 Australian Bureau of Statistics. (2019). 81040DO008_201718 - *Research and Experimental Development, Firms, Australia, 2017-18 [latest release]*. https://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/8104.02017-18?OpenDocument; Australian Bureau of Statistics (2019); Australian Bureau of Statistics. (2019). 81090DO007_201617 *Research and Experimental Development, Government and Private Non-Profit Organisations, Australia, 2016-17 [latest release]*. https://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/8109.02014-15?OpenDocument

214 The private sector can take a more active role in directing innovation towards environmental sustainability. The financial sector for example, is changing its investment decisions based on environmental stewardship and carbon emissions and encouraging industry to disclose their activities with the aim of motivating environmental transformations while maintaining their social licence to operate, see for example Task Force on Climate-Related Financial Disclosures (2019). *2019 Status Report, Task Force on Climate-related Financial Disclosures: Status Report*.

215 Clark, R., Reed, J. & Sunderland, T. (2018). Bridging funding gaps for climate and sustainable development: Pitfalls, progress and potential of private finance. *Land Use Policy,* 71, 335-346.

2.5.2 Opportunity: Equitably realising economic, social and environmental benefits

It is possible to pursue inclusive innovation with equitable distribution of benefits, and high potential on both economic multiplier and environmental change metrics by considering social, environmental and economic impacts at all stages of the innovation lifecycle. Particularly with the current COVID-19 backdrop, delivering sustainable growth requires investment in transformations and technological innovations that deliver on all three aspects of corporate social responsibility.

Preparing workforces for change

Innovation benefits, such as job creation and improvements in the nature of work, can outweigh costs such as job displacement when innovation adoption and development is paired with strategies to prepare workforces with the relevant skills to adapt to change. Businesses can establish a 'new normal', which skilfully employs innovation for job growth and improving the nature of work. In an equitable and purposeful environment, innovation can create jobs in future industries that support social needs, raise employment, expand consumption choices, and boost quality leisure time.[216] For instance:

- Digital innovations have dramatically changed the nature of work, allowing many to work from home to manage work and caring responsibilities. A wider range of employment choices driven by high-quality innovation improves diversity and inclusion, which have a positive impact on team performance, motivation and growth.[217] Studies on the psychology of innovation commonly find a positive correlation between innovative behaviour and employee's self-enhancement.[218]
- Innovations can create jobs that engage with community and civic values and bring joy in using creative capabilities.[219] Examples include socially innovative organisations, such as the Australian-invested Flying Doctors Service and Certified B Corporations.

By pursuing many of the above opportunities, Australia's workforce can be more resilient to job loss risks and enjoy the many benefits of innovation.

Mission-led sustainable development

A tripartite mission-led innovation, involving industry, government and the community, can address some of the social and environmental concerns of passive market-led innovation. It can provide long-term patient investment and catalyse the initial stages of innovation which are deemed too risky by private investors.[220] Private actors can invest once more certainty is established and diffuse innovation and its benefits across society. Public actors, such as the United Kingdom government[221] and the European Union,[222] have now developed mission-based industrial innovation strategies to tackle "grand challenges" such as climate change and other environmental issues, with longevity, scale and co-ordination as key elements of their strategies. This approach of public-private partnership can accelerate the transition of industries to cleaner technologies. Other countries that have demonstrated this over the last decade include Germany, Brazil and China with significant involvement of their development banks.

Australia could intentionally pursue a strategy where economic growth remains strong and inclusive, while using S&T to create new globally competitive, export-facing industries, and achieving net-zero emissions by 2050. CSIRO's *Australian National Outlook 2019* report identifies innovation in clean energy as one of the key shifts required to secure sustainable growth in the future. As the world transitions to a low-carbon economy, demand for Australia's traditional energy exports, such as coal, are predicted to decline. However, Australia can leverage its abundant natural resources and existing engineering capabilities to develop new low-emissions energy export opportunities.[223]

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216 Haworth, J. T., & Veal, A. J. (2004). *Work and leisure*. Psychology Press.; Zheng, C., Molineux, J., Mirshekary, S., & Scarparo, S. (2015). Developing individual and organisational work-life balance strategies to improve employee health and wellbeing. *Employee Relations*, 37(3), 354-379.

217 Lorenzo, R., Voigt, N., Schetelig, K., Zawdzki, A., Welpe, I., & Brosi, P. (2017). The Mix That Matters, Innovation Through Diversity. Boston Consulting Group. https://www.bcg.com/en-au/publications/2017/people-organization-leadership-talent-innovation-through-diversity-mix-that-matters.aspx; Hewlett, S., Marshall, M. & Sherbin, L. (2013). How Diversity Can Drive Innovation. *Harvard Business Review*. 2013 December Issue.

218 Purc, E., & Laguna, M. (2019). Personal Values and Innovative Behaviour of Employees. *Frontiers in psychology*, 10, 865.

219 Fields, Z. (2016). Using Creativity and Social Innovation to Create Social Value and Change. *Incorporating Business Models and Strategies into Social Entrepreneurship* (pp. 97-112). IGI Global.

220 Mazzucato, M. (2015). The Green Entrepreneurial State. *Working Paper Series SWPS 2015-28*. Science Policy Research Unit, University of Sussex. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2744602

221 Industrial Strategy Council. (2020). *Industrial Strategy Council: Annual Report*. https://industrialstrategycouncil.org/sites/default/files/attachments/ISC%20Annual%20Report%202020.pdf

222 European Commission. (2019). *Orientations towards the fist Strategic Plan for Horizon Europe*. https://ec.europa.eu/info/sites/info/files/research_and_innovation/strategy_on_research_and_innovation/documents/ec_rtd_orientations-he-strategic-plan_122019.pdf

223 CSIRO. (2019). *Australian National Outlook 2019*.

Australia's solar and wind energy resources are estimated to be 75% greater than its combined coal, gas, oil and uranium resources.[224] Australia could become a major exporter of hydrogen energy, with an estimated demand valued at between $2.6 billion and $13.4 billion by 2040, as well as opportunities for over 7,000 full-time equivalent jobs.[225] Transitioning Australia to renewable resources, energy generation, storage and grid support, will lower energy costs and increase productivity which can improve the competitiveness of Australian businesses and reduce financial strain on households. Australia could develop a large clean energy export market by accelerating the widespread deployment of mature and demonstrated green technologies in sectors that are easy to decarbonise in the short term, and by rapidly developing and commercializing technologies for harder-to-abate sectors.[226] Industry groups and stakeholders also identified rolling out low-emissions technologies as a significant opportunity to generate jobs and economic growth in the recovery from COVID-19.[227]

224 Beyond Zero Emissions. (2015.) *Renewable Energy Superpower: Zero carbon Australia*. https://bze.org.au/wp-content/uploads/renewable-energy-superpower-bze-report-2015.pdf

225 ACIL Allen Consulting. (2018). *Opportunities for Australia from Hydrogen Exports*. ARENA. https://arena.gov.au/assets/2018/08/opportunities-for-australia-from-hydrogen-exports.pdf

226 ClimateWorks. (2020). *Decarbonization Futures: Solutions, actions and benchmarks for a net zero emissions Australia.* https://www.climateworksaustralia.org/resource/decarbonisation-futures-solutions-actions-and-benchmarks-for-a-net-zero-emissions-australia/

227 Foley, M. (2020) Ambitious climate action a 'double win' for economy in coronavirus recovery. *Sydney Morning Herald*. https://www.smh.com.au/politics/federal/ambitious-climate-action-a-double-win-for-economy-in-coronavirus-recovery-20200402-p54gj3.html

3 Conclusion and the need for action

While S&T innovation has always played a key role in Australia's productivity and growth, the current COVID-19 crisis and weak economy mean that S&T innovation is more important than ever. Although budgets will be constrained in the coming years, Australian can rely on S&T innovation to help lead the economic recovery and build future resilience.

During this COVID-19 crisis, Australian businesses have an opportunity to reflect on their long-term goals, to make decisions aligned to achieving them, and to determine how to use S&T innovation as part of the solution. Now is the time to overcome complacency and reassess the validity of the long-held expectation that productivity and economic growth will continue without marked change. Australian businesses can set an agenda for mission-led innovation, supported by a cohesive strategy to build national capabilities and drive economic recovery and future resilience.

Importantly, although this report focuses on opportunities for businesses and industry, this shift requires a coordinated effort involving both the public and private sectors. The motivation, expertise, thinking and coordination required to achieve this positive future described in this report extends beyond any single organisation or sector.

This shift also requires continuous evaluation, learning and measurement, including the links between innovation investment and its intended impacts. Building the evidentiary basis used for decision-making across all sectors may require an 'innovation evaluation' toolkit, developed by combining various existing empirical methodologies, data sources and collaborative efforts.[228] Drawing on a range of different approaches, Australia's research sector might lead the development of a body of knowledge around iterative processes of evaluation and improvement, often described as the 'science (or economics) of science and technology innovation'.[229]

While this report summarises the vast existing literature on the economics of innovation, the *Value of science and technology* report does not address every challenge in Australia's innovation system, nor does it offer all the solutions. The report also makes no presumption about specific policies needed to implement the opportunities or to address the challenges. Instead, the report aims to motivate thinking and discussion and guide strategic investment planning in Australian businesses. Ultimately, it aims to inspire a collective and coordinated response to lead Australia towards an ambitious but achievable innovation-driven future.

228 Examples include: ATSE. (2019). *Innovation metrics literature review*; Australian Bureau of Statistics (2019). *Business Longitudinal Analysis Data Environment (BLADE)*; OECD & Gallup-Healthways subjective wellbeing surveys; CSIRO. (2020). *Impact Evaluation Guide*; New Zealand Treasury. (2018). *Our people - Multidimensional wellbeing in New Zealand (AP 18/04)*; UK Office for National Statistics. (2011). *Measuring Subjective Well-being for Public Policy*; Largent, M. A. & Lane, J. I. (2012). STAR METRICS and the Science of Science Policy. *Review of Policy Research*, 29(3), 431-438; Lane, J. I., Owen-Smith, J., Rosen, R.F., & Weinberg, B.A. (2015). New linked data on research investments: Scientific workforce, productivity, and public value. *Research policy*, 44(9), 1659-1671. Dodgson M, Hughes A, Foster J and Metcalfe S (2011). Systems thinking, market failure, and the development of innovation policy: The case of Australia. *Research Policy*, 40(9), 1145-1156.

229 For an excellent overview of this field refer to: Lane, J. I., Fealing, K. H., Marburger III, J. H., & Shipp, S. S. (2011). *The science of science policy: A handbook*. Stanford University Press.

Appendix A: Concepts and definitions

Innovation

In accordance with the OECD (2018) Oslo Manual, the report defines innovation as a new or improved product or process (or a combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process).[230] This also aligns with the definition offered by Industry Innovation and Science Australia, whereby innovation is fundamentally doing something differently and creating value as a result.[231]

The OECD (2018) Oslo Manual breaks down innovation into two types:

- product innovation is a new or improved good or service that differs significantly from the business's previous goods or services and that has been introduced on the market
- business process innovation is a new or improved business process for one or more business functions that differs significantly from the business's previous business processes and that has been brought into use by the business.

This report focuses on both types - product and process innovation in S&T. In Australia, innovation is measured in the ABS' Business Characteristics Survey and reported in its publication *Characteristics of Australian Business*.[232]

Innovation systems

Innovation systems refer to complex and dynamic, open networks of many diverse actors who interact to diffuse innovations.[233] Institutions at multiple levels are engaged in innovation systems: the economy, industries, businesses, research groups or teams, and even individuals (such as individual researchers making breakthroughs). These systems are influenced by policies that influence the behaviour of businesses and their pathways to innovation.[234] These concepts are formally derived from innovation systems theory stress that innovation is not a linear, sequential process, but involves many interactions and feedbacks in knowledge creation and use.[235] Organisations need to share information collected with wider sets of actors including other public-sector organisations and members of the public to support decision making, accountability and co-innovation and facilitate value creation elsewhere in the economy.

Technology

Fundamentally, technology offers new ways of doing things – creating more value with less input – that are disruptive (replacing or enhancing previous ways of doing) and ultimately create lasting change. As outlined in McKinsey's (2013) Disruptive Technologies report, highly disruptive technologies have several attributes that they rank highly in: rate of breakthroughs; scope of impact; economic value, for instance, greater profits and GDP contributions; potential for economic impact in terms of how people live and work, how businesses operate and national comparative advantages.[236,237] Although the scope of this report is on innovation in science[238] and technology, it necessarily contextualises this within the broader context of technologies that aid business process transformations.

230 A product innovation is a new or improved good or service that differs significantly from the business's previous goods or services and that has been introduced on the market. A business process innovation is a new or improved business process for one or more business functions that differs significantly from the business's previous business processes and that has been brought into use by the business. Source: OECD (2018). Oslo Manual 2018: Guidelines for Collecting, Reporting and Using Data on Innovation, https://www.oecd.org/science/oslo-manual-2018-9789264304604-en.htm

231 Industry Innovation and Science Australia. (2016). *Performance Review of the Australian Innovation, Science and Research System*.

232 Australian Bureau of Statistics. (2020). *Characteristics of Australian Business, 2018-19.* https://www.abs.gov.au/statistics/industry/technology-and-innovation/characteristics-australian-business/latest-release#data-download

233 Industry Innovation and Science Australia. (2016). *Performance Review of the Australian Innovation, Science and Research System*.

234 Mazzucato, M. (2015). *The Entrepreneurial State (US Edition).* New York: PublicAffairs.

235 Innovation systems can be delineated by industry, technology, or geography and are often interrelated, with local systems linked to national and global systems. Measurement usually collects data at the business level, with the resulting data then aggregated to provide results at the national or industry level. OECD (2018). Oslo Manual 2018: Guidelines for Collecting, Reporting and Using Data on Innovation, https://www.oecd.org/science/oslo-manual-2018-9789264304604-en.htm. See also Freeman, 1987; Lundvall, 1992; Nelson [ed.], 1993; OECD, 1997

236 A country is said to have a revealed comparative advantage in practice, if they export more of a good as a percentage of the country's total exports than the world economy exports of the same good as a percentage of total world exports.

237 McKinsey Global Institute. (2013). Disruptive technologies: Advances that will transform life, business, and the global economy. *McKinsey Digital*. https://www.mckinsey.com/business-functions/mckinsey-digital/our-insights/disruptive-technologies

238 Science refers to the physical sciences that principally include physics, mathematics, biology, chemistry and environmental science. Science is fundamentally concerned with the need to understand complex systems and predict their behaviours.

Research and development (R&D)

Research is the process of exploration and discovery through which new knowledge is created and its applications developed to produce novel technologies, products, services and jobs. Covering multiple disciplines – especially in science, technology, engineering and mathematics (STEM) – and typically involving collaboration[239], R&D is the pith of innovation. Although R&D is an important part of innovation, there is an important role played by patents and the broader transformation of business models, which occurs as innovations are effectively developed and integrated into industry. R&D also contributes to a business's absorptive capacity, namely its ability to recognise the value of new, external information, assimilate it and apply it to commercial ends, which is considered critical to innovation performance.[240]

Commercialisation

Commercialisation is the process of translating R&D and other early-stage innovations into products and services that are available to the market. This involves a combination of product development, business strategy and growing adoption in the market. Typically there are multiple stages: developing proprietary technology R&D; distribution (including financing, IP, sales, marketing, further research); application development and product launch; proprietary manufacturing of technology, platforms and systems; and eventually full-scale production, transitioning to lean production.[241] Other innovations may be purchased and incorporated into existing business processes or used to develop more productive ways of doing things.

Adoption and diffusion

Adoption refers to the process of growth in the purchases or use of these commercialised innovations in the market. The technology adoption process, on average, begins slowly before ramping up quite quickly – an effect that may then experience a slow-down if the innovation has been 'hyped up'. The adoption of a new or improved product or business process by a business that is part of an enterprise group is an innovation.[242] Adoption continues as costs decline with increased scale of production and perhaps further technological advances along the way. Eventually, once the innovation has been widely adopted, the adoption rate slows and begins to plateau – this is the "S-curve" of technology adoption. Diffusion is the process by which an innovative idea or product spreads and gains momentum through a population or social system, the result being that the people adopt the new idea or product.[243]

Productivity

According to the Productivity Commission, productivity is a measure of the rate at which output of goods and services are produced per unit of input (labour, capital, raw materials, etc.). It is calculated as the ratio of the quantity of output produced to some measure of the quantity of inputs used. Contributing factors include technological improvements, economies of scale and scope, workforce skills, management practices, changes in other inputs (such as capital), competitive pressures and the stage of the business cycle. Labour productivity is the ratio of output to hours worked. Over the long term, wages generally grow in step with labour productivity and as such, it is a key determinant of income growth. [244] MFP is the ratio of output to combined input of labour and capital; each weighted by their share of total factor income.[245] MFP is commonly regarded as the superior measure of technological change and efficiency improvements.[246]

239 Collaboration is defined in the Australian Bureau of Statistics' (1) Characteristics of Australian Business publication as "Active joint participation with other organisations which involves some sharing of technical or commercial risk. Straight free-for-service arrangements are not deemed to be collaborative and are therefore excluded." Australian Bureau of Statistics. (2020). *Characteristics of Australian Business, 2018-19*. https://www.abs.gov.au/statistics/industry/technology-and-innovation/characteristics-australian-business/latest-release#data-download; and (2) Business Characteristics Survey form as "To collaborate is to participate in joint projects with other businesses or organisations (including wider parts of this business's enterprise group). Each participant does not need to benefit commercially." Australian Bureau of Statistics. (2019). *Business Characteristics Survey 2018-19*. https://www.ausstats.abs.gov.au/ausstats/subscriber.nsf/0/3352BE77F10FE46DCA2585920016C883/$File/8167.0%20-%20business%20characteristics%20survey%202018-19%20questionnaire.pdf.

240 Cohen, W.M. & Levinthal, D.A. (1990). Absorptive Capacity: A New Perspective on and Innovation Learning. *Administrative Science Quarterly,* 35(1), 128–152.

241 IP Australia. (2019). *Understand Commercialisation*. https://www.ipaustralia.gov.au/understanding-ip/commercialise-your-ip/understand-commercialisation

242 OECD (2018). *Oslo Manual 2018: Guidelines for Collecting, Reporting and Using Data on Innovation*. https://www.oecd.org/science/oslo-manual-2018-9789264304604-en.htm

243 Rogers, E.M. (1962). *Diffusion of innovations (1st ed.)*. New York: Free Press of Glencoe.

244 Productivity Commission. (2020). *Productivity Insights February 2020*. https://www.pc.gov.au/research/ongoing/productivity-insights/recent-productivity-trends/productivity-insights-2020-productivity-trends.pdf

245 Australian Bureau of Statistics. (2019). 5260.0.55.002 - *Estimates of Industry Multifactor Productivity, 2018-19 [latest release]*. https://www.abs.gov.au/ausstats/abs@.nsf/mf/5260.0.55.002

246 Productivity Commission (2020). *Productivity Insights February 2020.* https://www.pc.gov.au/research/ongoing/productivity-insights/recent-productivity-trends/productivity-insights-2020-productivity-trends.pdf

Appendix B: The innovation cycle

Despite the widespread agreement on the importance and value of innovation, the pathways through which innovation creates value and impact are complex and messy. The analysis is structured around an innovation cycle developed to illustrate, describe and assess the pathways through which innovation creates value and impact. Each stage has its own, self-reinforcing cycle whereby innovation catalyses further advancements and new ideas. A well-functioning innovation ecosystem involves coordinated innovation support from research organisations, start-ups, businesses, government and venture capitalists or other investors.[247] Moving through the cycle effectively requires incentivised collaboration and knowledge sharing, to provide earlier stages with the foresight needed to understand end-user needs. By working together, stakeholders can engage in iterative co-invention and design to maximise value and impact.

Several elements in the cycle are required in different forms at multiple stages, notably capital investment and knowledge development. While investment is needed at every stage of the framework, it is particularly important at the start of the framework to support R&D. Knowledge and capabilities for innovation also develop at multiple stages of the innovation cycle, creating feedback loops that drive the innovation cycle. In some cases, the productivity and economic impacts are bypassed in pursuit of wider social and environmental impacts, for instance where technologies are designed to directly meet social need rather than being sold in markets. Organisations may also enter later in the cycle (e.g. process improvements via incremental adoption), thereby contributing to and supporting the economic impacts of innovation.

The innovation cycle has four core stages and eight steps as follows:

Stage 1: Inception

Ideas, needs and investment: Innovation begins with a coalescing process of creating ideas, identifying market-relevant and societal needs, and raising capital investment for early development. Typically, those innovations that ultimately achieve successful scale-up and ongoing profitability have a clear, though adaptable, view of how the innovation will solve specific problems or fill gaps in the current market. Investment needs to be strategically aligned with long-term strategic objectives for maximum impact.

Stage 2: Value creation

R&D and application: Although necessary at all steps of the innovation cycle, public and private investment in R&D and accompanying non-R&D innovation (e.g. business model adaptation) is essential for innovation. In the process of application, innovations are developed to the point of practical viability in solving the societal or market need for which they are intended. When sold in markets, this process is commercialisation, though products, services and knowledge may also be applied directly for public need without involvement in commercial transactions.

Knowledge and capabilities: The previous inception stages involve self-reinforcing cycles of knowledge and capability development. As these intangible knowledge resources grow, stakeholders (beyond researchers and investors) begin to see the value of early innovation developments as new solutions and opportunities are presented. For innovators, this stage increases the likelihood of making path-breaking future innovations. For businesses, ongoing competitive advantage requires continuous value creation and innovation: either offering more consumer value for the same price or justifying higher prices.[248] Workers too can perform a wider range of value-add tasks and to produce more with less, as their capabilities and skills increase. Knowledge and capabilities are extended via network effects, spillovers and collaboration between researchers, businesses and end-users. In turn, other innovations are derived from activities that involve the practical application of existing or newly developed information and knowledge.

247 Budden, P. & Murray, F. (2019). *MIT's Stakeholder Framework for Building & Accelerating Innovation Ecosystems*, https://innovation.mit.edu/assets/Innovation-Stakeholder-Framework.pdf

248 Mazzucato, M. (2015). *The Entrepreneurial State (US Edition)*. New York: PublicAffairs.

Stage 3: Value capture

Adoption and diffusion: Value is captured in an economic sense when the value created through R&D is translated into products and services that are adopted throughout the economy. Businesses can adapt their business models, strategies and operations to these innovations. As more businesses do this, their experiences and models are shared with wider sets of actors across the public and private sectors, leading to process transformation across industry. As innovations are diffused across industries, they may disrupt existing processes and activities and creates new ways of doing things. Innovation diffusion can also create knowledge flows that lead to further innovations.

Transformation and improvements: Innovations enable businesses to produce higher-quality outputs with fewer inputs; to evolve their products and services to meet new markets and tackle more sophisticated problems. Knowledge and capability development combine with process transformations to increase the productivity of workers and businesses. These effects play out at multiple levels throughout the economy, from individual workers to businesses, industries and the nation. Repetitive tasks can be replaced by technologies to make remaining tasks more human-centred and intuitive; with potential flow-on effects to individual workers' satisfaction, also improving their motivation and their productivity.[249] Some innovations will contribute directly to social and environmental outcomes (without necessarily having a strong impact on economic outcomes), though this bottom part of the innovation cycle tends to be reinforcing, as shown by bidirectional arrows.

State 4: Wider impacts

Productivity and economic impacts: Productivity improvements and increases in the economic value of final products and services drive growth and employment throughout the economy. Technological progress contributes directly to gross domestic product (GDP) and has indirect effects via capital and labour growth, which can experience virtuous reinforcing cycles. As the economy grows, confidence and businesses' performances improve, which makes more resources available for reinvestment and eventually encourages more investment in innovation. Since many of the benefits of innovation are not currently fully captured by productivity and economic statistics, much social value is created from innovation beyond what is recorded.

Social and environmental impacts: Innovations solve many of the practical problems people face in their lives, whilst extending the frontier of what is possible to create new ways of doing and seeing. Fundamentally, innovations are intended to improve people's quality of life; to allow them to do more and enjoy more of what they have. From the previous stage, economic growth and productivity also has the effect of raising incomes, whilst generating higher quality products and services. Innovation's ability to improve the lives of Australians depends on quality education and training to build resilience to change, and redistribution of the gains from innovation with progressive social support policies. S&T innovations solve many environmental challenges, for instance leading the way in addressing climate change adaptability. Innovative productivity improvements– by using fewer inputs, which ultimately come from natural sources, to produce the same outputs – also improve natural resource sustainability. Crucially, innovation improves the ability to mitigate large, unpredictable risks (e.g. pandemics, environmental crises) and solve specific problems (e.g. harmful wastes).

Potential reinvestment: Economic and employment growth drive economic output; creating more consumption and investment, including in innovation again (see stage one above). New and improved products and services shape markets and other institutions that can support future innovation as the cycle continues. Meanwhile, demonstrating and capturing the value of innovation outputs establishes the case for further investing in innovation via a coordinated stakeholder approach. Past innovations create more ideas for future innovations, and so the tangible and intangible assets built throughout the innovation cycle are reinvested again and again to create further cycles of value creation, capture and wider benefits.

249 Bakker, A. B., & Oerlemans, W. (2011). Subjective well-being in organizations. *The Oxford handbook of positive organizational scholarship*, 178-189.

Appendix C: Challenges with measuring and interpreting value creation

While this report cites evidence on the features and impact of value creation and capture, there are challenges and disagreement about measuring and interpreting the interaction of variables that influence productivity growth and economic progress. For example, a recent PwC study argued that the relationship between business innovation and economic success is "tenuous at best".[250] While there are clear correlations in some areas, such as the impact of diversity on innovation (discussed in 2.5), the empirical evidence in other areas can be more nebulous.

A detailed business-level analysis of SME productivity using big data and large, high-quality administrative datasets provided by Nathan & Rosso (2019) shows that there is a need for better innovation data to capture mechanisms and behaviours within businesses.[251] The authors conclude that "technological change plays a key role in productivity growth, yet it is hard to capture with conventional data".[252]

A few examples of challenges to measurement and interpretation include:

- **Definitions:** Differences in scope and measurement of factors can affect the results, interpretation and comparability of studies. For example, MFP indexes reflect a variety of factors, including the effects of technological change, changes in processes and management practices, reallocation of inputs, economies of scale, government policies, external shocks (e.g. weather conditions) and measurement errors.[253] It can be particularly difficult to disaggregate both the relative contributions of each of these factors towards the MFP result as well as the relative benefits from R&D-related innovation compared to non-R&D innovation.[254]
- **Diffusion lag and intangibles:** The aggregate improvement from S&T can be difficult to estimate since benefits from the diffusion of research, knowledge and innovation can take decades to materialise.[255] Similarly, most economic statistics are based on prices and direct expenditures, while a lot of new technologies such as smartphones and social networks offer consumer value at very low monetary costs, e.g. Netflix. It can be difficult to measure the full extent of non-monetary benefits that science and technologies create. Brynjolfsson and Oh highlight for example that most traditional measures overlook broader welfare gains of digital services.[256]
- **Inferring causality:** To make evidence-based decisions, causality is sometimes inferred from a detailed analysis of context and consideration of alternative narratives.[257] This is because empirical studies describe the correlation between factors, events or interactions of interest; and it is difficult to establish and control experiments to fully describe the complex interaction of factors that influence behaviours and outcomes at the business, industry, national and international level. For these reasons, business-level strategies and policies should proceed with caution if made on aggregate-statistics alone.

Such measurement challenges prevent us from accurately quantifying the value of innovation and its contribution to productivity and economic growth. This issue is also linked to the productivity paradox of the next appendix, where low average recorded productivity in advanced economies combined with measurement issues are often cited to explain the discrepancy between technological growth and productivity slowdown observed today.

250 PWC. (2017). *Reinventing Innovation – Five Findings to Guide Strategy Through Execution*. https://www.pwc.com/gr/en/publications/assets/innovation-benchmark-report.pdf

251 Nathan, M. & Rosso, A. (2019). *Measuring the effect of innovation on productivity inside firms, CEP Discussion Paper No 1607*. http://cep.lse.ac.uk/pubs/download/dp1607.pdf

252 The authors combine UK administrative microdata, media and website content to develop experimental metrics – new product/service launches – for a large panel of SMEs.

253 Australian Bureau of Statistics. (2018). *Estimates of Industry Multifactor Productivity. About Productivity Statistics*. https://www.abs.gov.au/ausstats/abs@.nsf/Lookup/5260.0.55.002main+features22016-17

254 Traditional measures of productivity may also be less meaningful now given structural changes in the global economy towards technology-related goods and services. That is, contributions from technological progress might also be reflected in the growth in gross-value-add from technology companies. Source: DIIS (2019). Innovation Metrics Review: Recommendations, https://www.industry.gov.au/data-and-publications/innovation-metrics-review

255 OECD. (2005). The Measurement of Scientific and Technological Activities. *Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data.* Third Edition, prepared by the Working Party of National Experts on Scientific and Technology Indicators, OECD, Paris, para. 146.

256 Brynjolfsson, E., & Oh, J. (2012). *The attention economy: measuring the value of free digital services on the Internet*. MIT Initiative on the Digital Economy. http://ide.mit.edu/research-projects/attention-economy-measuring-value-free-goods-internet

257 Morck, R., & Yeung, B. (2011). *Economics, History and Causation. NBER Working Paper No. 16678*. https://www.nber.org/papers/w16678; World Economic Forum. (2016). *Correlation and Causality in Economics: Can We Prove It?* https://www.weforum.org/agenda/2016/05/correlation-and-causality-in-economics-can-we-prove-it/

Appendix D: Highlights of Australian innovation

This section seeks to supplement the innovation cycle by providing examples of Australian innovation breakthroughs and case studies. The case studies focus on Australia's well-known and lesser-known innovations and are intended to illustrate the different mechanisms of the innovation cycle including the drivers, paths and impacts. The case studies also seek to highlight the challenges of innovating, including where lessons have been learned and improvements made.

A rich history of innovation breakthroughs

DATE	INNOVATION	IMPACTS	ECONOMIC IMPACT	SOCIAL IMPACT	ENVIRONMENTAL IMPACT
1889	Electric drill	Established underlying technology for the modern (portable) electric tool, which has a myriad of applications, from mining to everyday DIY projects. The global hand and power tools market was estimated to be worth USD 51 billion in 2017.[258]	✓		
1913	X-ray crystallography	Application in molecular structural analysis. Enabled discovery of the DNA double helix by Rosalind Franklin.[259] Crystallography also is extremely relevant in many different industries, such as pharmaceuticals, mining, agro-food, computer and electro-mechanical.[260] Since the work of the Braggs, 48 Nobel Prizes have been given in the field of crystallography.	✓		
1928	Electronic pacemaker	1.1 million pacemakers were implanted in 2016, with a forecast of 1.43 million in 2023.[261] The 2017 estimate for the global cardiac pacemaker market was USD 6 billion and is predicted to grow to USD 11.1 billion by 2026.[262]	✓	✓	
1943	Aerogard	Protects individuals from mosquito bites, allowing one to enter insect-infected areas and avoid disease transmission. Aerogard has a market share of 50% in Australia.[263]	✓		
1944-1949	Birch reduction of aromatic compounds	Contributed to the commercial synthesis of oral contraceptives (step 2 out of 6).[264] Oral contraceptives are used by over 100 million women worldwide.[265] It is also listed on the WHO list of essential medicines.[266] Was a key ingredient in the women's rights revolution and the sexual revolution.[267]	✓	✓	

258 Grossman, D. (2017). The Handful of Megabrands That Make Most of the World's Tools. *Popular Mechanics*. https://www.popularmechanics.com/technology/gear/a28359/megabrands-tools-graphic/.

259 Franklin, R.E. & Gosling, R.G. (2003). Molecular configuration in sodium thymonucleate: 1953. *Nature,* 421(6921), 400-401

260 United Nations Educational, Scientific and Cultural Organisation. (2013). *Crystallography matters!* http://www.unesco.org/new/fileadmin/MULTIMEDIA/HQ/SC/pdf/sc_crystallography_Matters_EN.pdf

261 Statista. (2016). *Global number of pacemakers in 2016 and a forecast for 2023 (in million units)*. https://www.statista.com/statistics/800794/pacemakers-market-volume-in-units-worldwide/

262 Coherent Market Insights. (2019). Global Cardiac Pacemaker Market to Surpass US$ 11.1 Billion by 2026. *PR Newswire*. https://www.prnewswire.com/news-releases/global-cardiac-pacemaker-market-to-surpass-us-11-1-billion-by-2026--300898737.html#:~:text=Global%20Cardiac%20Pacemaker%20Market%20to%20Surpass%20US%24%2011.1%20Billion%20by%202026,-News%20provided%20by&text=SEATTLE%2C%20Aug.,period%20(2018%20%E2%80%93%202026).

263 Christensen, N. (2014). New RID insect repellent campaign asks for nomination to trek through Amazon in their undies. *Mumbrella*. https://mumbrella.com.au/new-rid-insect-repellant-campaign-asks-nomination-trek-jungle-theirunderwear-249794

264 Australian Academy of Science. (2007). *Arthur John Birch 1915-1995*. https://www.science.org.au/fellowship/fellows/biographical-memoirs/arthur-john-birch-1915-1995

265 Mosher, W.D. et al. (2004). Use of contraception and use of family planning services in the United States: 1982 - 2002. *Advanced Data,* 350, 1-36.

266 World Health Organisation. (2015). *WHO Model List of Essential Medicines (19th List)*. https://www.who.int/medicines/publications/essentialmedicines/en/

267 Harris, G. (2010). The Pill Started More Than One Revolution. *The New York Times.* https://www.nytimes.com/2010/05/04/health/04pill.html

DATE	INNOVATION	IMPACTS	ECONOMIC IMPACT	SOCIAL IMPACT	ENVIRONMENTAL IMPACT
1952	Atomic absorption spectroscopy	Contributed to advances in chemical analysis and is used today in a variety of industries, including medicine, mining and agriculture. Estimates in 1977 claimed that the benefit to the Australian economy was over $200 million (overseas royalties, setting up of industry and productivity increases in enterprises).[268] The global market for AAS instruments alone is $300 million.[269]	✓		
1953	Electronic flight data recorder (black box)	Have been a required instalment in all Australian aviation since 1960.[270] Dr Warren did not receive any royalties for the invention and was not officially recognised until 2002 when he was made an Officer of the Order of Australia (AO).[271] Despite being mandated in all commercial aircraft built in the western world, the Australian Department of Defence only received a payment of £1,000.[272]	✓	✓	
1960	Plastic spectacle lenses	Led to lighter and more durable glasses. The eyeglasses industry is estimated at AUD 41 billion,[273] with plastic lenses being one of the most common types of spectacle lenses.	✓		
1962	Ultrasound scanner	Global ultrasound market in 2018 was AUD 9.3 billion.[274] Has resulted in a safer technology, which does not subject the patient to ionising radiation, unlike X-ray and CT scans.	✓	✓	
1965	Inflatable escape slide and raft	Invented by Jack Grant of Qantas and is now standard safety equipment on almost all major airlines.[275]	✓	✓	
1978	Cochlear implant	Allows individuals to understand speech about 8 times better than without the implant.[276] Cochlear Ltd., the business set up to commercialise the cochlear implant, had annual revenue of AUD 1.24 billion and net income of AUD 224 million in 2017.[277]	✓	✓	
1978	Permaculture	Bill Mollison and David Holmgren revolutionised the practice of permaculture and were the catalyst for the modern sustainable agriculture movement		✓	✓
1979	RaceCam	Became a staple in Australian motor racing broadcasting in the 1980s and 1990s and later expanded internationally and to other sports, including baseball and skiing.[278]	✓		
1988	Polymer bank notes	Led to notes which could not be forged, were more durable, less likely to carry disease and more environmentally friendly. Polymer banknotes have been adopted in 22 countries and have saved the RBA over $1 billion since adoption.[279]	✓	✓	✓

268 Ward, C. (2011). Atomic absorption spectroscopy. *CSIROpedia.* https://csiropedia.csiro.au/atomic-absorption-spectroscopy/#:~:text=AAS%20allows%20the%20measurement%20of,and%20laboratories%20throughout%20the%20world.

269 Ward, C. (2011) Ibid.

270 Defence Science and Technology Organisation. (2005). *Dave Warren – Inventor of the black box flight recorder*. https://web.archive.org/web/20100522041848/http://www.dsto.defence.gov.au/page/3383/

271 Charleston, L.J. (2019). How an Aussie scientist came up with the idea of the black box flight recorder. *News.com.au*. https://www.news.com.au/travel/travel-updates/incidents/how-an-aussie-scientist-came-up-with-the-idea-of-the-black-box-flight-recorder/news-story/ceb834e5e37200b4016ec7623db72659.

272 Faulkner, J. (2014). The black box: an Australian invention that nearly didn't happen. *The Conversation*. https://theconversation.com/the-black-box-an-australian-invention-that-nearly-didnt-happen-25435.

273 Swanson, A. (2014). Meet the Four-Eyed, Eight-Tentacled Monopoly That is Making Your Glasses So Expensive. *Forbes*. https://www.forbes.com/sites/anaswanson/2014/09/10/meet-the-four-eyed-eight-tentacled-monopoly-that-is-making-your-glasses-so-expensive/#6fdfc61e6b66

274 Marketandmarkets. (2018). Ultrasound Market by Technology (Diagnostic, FUS, SWL), Display (Color, B/W). *Portability (Trolley, Compact, Portable, POC), Application (Radiology, OB/GYN, Urology, Cardiology, Orthopedic), End user (Hospitals, ACC, Diagnostic Centers) – Forecast to 2023*. https://www.marketsandmarkets.com/Market-Reports/ultrasound-market-467.html

275 Australian Institute of Company Directors. (2004). *Inventing Australia: 1901-2001 Innovation*. http://www.companydirectors.com.au/director-resource-centre/publications/company-director-magazine/2000-to-2009-back-editions/2004/april/inventing-australia-19012001-innovation

276 Gaylor, J.M. et al. (2013). Cochlear Implantation in Adults. A Systematic Review and Meta-analysis. *JAMA Otolaryngology Head & Neck Surgery*, 139(3), 265–272.

277 Cochlear Limited. (2017). *2017 Cochlear Limited Annual Report*. https://www.cochlear.com/b0dffcb0-9826-4c99-9d58-ad7a760bddac/en_corporate_cochlear_annualreport2017_1.78mb.pdf?MOD=AJPERES&CONVERT_TO=url&CACHEID=ROOTWORKSPACE-b0dffcb0-9826-4c99-9d58-ad7a760bddac-lTJByF-

278 Masige, S. (2020). Google Maps turns 15 this month, and it started in Australia. Here are 5 tech innovations with Aussie roots. *Yahoo Finance*. https://au.finance.yahoo.com/news/google-maps-turns-15-month-035631985.html

279 Ward, C. (2011). Polymer Bank Notes. *CSIROpedia.* https://csiropedia.csiro.au/polymer-banknotes/; Wakefield, M., Delaney, L. & Finlay, R. (2019). *A Cost-benefit Analysis of Polymer Banknotes*. Reserve Bank of Australia. https://www.rba.gov.au/publications/bulletin/2019/dec/a-cost-benefit-analysis-of-polymer-banknotes.html

DATE	INNOVATION	IMPACTS	ECONOMIC IMPACT	SOCIAL IMPACT	ENVIRONMENTAL IMPACT
1989	PERC solar cell technology	Took solar cell efficiency from 17% to 25% and have a 90% share of silicon-based solar cell manufacturing capacity.[280] Flow-on benefits to Australia are estimated to be over $8 billion and could lead to a 5% reduction in greenhouse gas emissions by mid-2020s.[281]	✓		✓
1991	Extended wear contact lenses	CIBA Vision and Novartis, the two businesses that collaborated with CSIRO to commercialise the technology, merged in mid-2019 to form Alcon, which is worth over 28 billion Swiss francs.[282] Extended wear contact lenses make up the second-largest market segment of the USD 7.24 billion contact lens global market.[283]	✓		
1992	Wi-fi	Wi-fi estimated to contribute $2 trillion in global economic value in 2018.[284] The value is estimated to reach $3.5 trillion by 2023.[285] CSIRO has earned more than $430 million in royalties for its role in the development of WLAN.[286]	✓		
1995 -1999	Zanamivir/ Relenza	Is available in 70 countries and works against all strains of the influenza virus. Neuraminidase inhibitors, such as Zanamivir, have global annual sales over AUD 3 billion.[287]	✓	✓	
Late 1990s	RNAi technology	Technology that silences gene expression. Heralded as a breakthrough in molecular biology with application in plant, animal and human health science.[288] CSIRO have issued more than 30 research and commercial licences for the technology. Has environmental benefits too, such as improving biofuels and improving the sustainability of certain crops.[289]		✓	
1999	Spray-on skin	Uses 98% less skin to treat burns compared to skin grafts (the usual treatment).[290] It heals the affected skin at a faster rate and creates less scarring than traditional methods.[291] Prof Wood established Avita Medical to commercialise her invention. Sales of the RECELL System, which prepares Spray-On Skin Cells, had total sales of AUD 7.7 million in 2018-2019.[292]	✓	✓	
2003	Google Maps	Revolutionised the use of maps and navigation. Google Maps now has more than one billion users worldwide.[293] Google has 7,000 staff dedicated to Google Maps and the service is estimated to earn USD 4.86 billion in 2020 and over USD 11 billion in 2023.[294]	✓		

280 Wenham, S. (2017). Hydrogenation a hundredfold solar cell booster shot. *Ecogeneration.* https://www.ecogeneration.com.au/hydrogenation-a-hundredfold-solar-cell-booster-shot/

281 Green, M.A. (2016). *Estimate of Economic Benefits to Australia of Past Australian Photovoltaic Research (information paper)*. UNSW Australia.

282 Smith, A. (2019). Novartis continues to 'reimagine' itself, as Alcon spin-off completed. *PharmaTimes*. http://www.pharmatimes.com/news/novartis_continues_to_reimagine_itself,_as_alcon_spin-off_completed_1284192

283 MarketsandMarkets. (2018). *Contact Lenses Market by Model (Daily Wear, Extended Wear), Design (Monovision, Spherical, Multifocal, Toric), Material (PMMA, Hybrid, Silicone Hydrogel), Application (Orthokeratology, Decorative Lenses), Distribution Channel - Global Forecast to 2023.* https://www.marketsandmarkets.com/Market-Reports/contact-lenses-market-204541962.html

284 Wi-Fi Alliance. (2018). *Wi-Fi Global Economic Value Reaches $1.96 trillion in 2018.* https://www.wi-fi.org/news-events/newsroom/wi-fi-global-economic-value-reaches-196-trillion-in-2018

285 Telecom Advisory Service. (2018). *The Economic Value of Wi-Fi: A Global View*. https://www.wi-fi.org/downloads-registered-guest/Economic%2BValue%2Bof%2BWi-Fi%2B2018.pdf/35675

286 IP Australia (2016) *CSIRO's WLAN patent*.

287 Ward, C. (2011) Relenza®. *CSIROpedia.* https://csiropedia.csiro.au/relenza/

288 CSIRO. (2019). *Australian RNAi technology: silencing gene expression for plant, animal and human health science*. https://www.csiro.au/en/Research/Farming-food/Innovation-and-technology-for-the-future/Gene-technology/RNAi

289 Koreis, D. (2018). *RNAi: the silencing achiever*. CSIRO. https://www.csiro.au/en/News/News-releases/2018/RNAi-the-silencing-achiever>.

290 Fox, M. (2018). FDA approves first spray-on skin treatment for burns. *NBC News*. https://www.nbcnews.com/health/health-news/fda-approves-first-spray-skin-product-n911976

291 Minion, L. (2017). Australian developed spray-on skin for burns treatment seeks FDA approval. *Healthcare IT*. https://www.healthcareit.com.au/article/australian-developed-spray-skin-burns-treatment-seeks-fda-approval

292 Avita Medical. (2019). *Concise Financial Report 2019*. https://www.avitamedical.com/uploads/pdf/2019-Concise-Annual-Report.pdf

293 Gibbs, S. (2015). Google Maps: a decade of transforming the mapping landscape. *The Guardian*. https://www.theguardian.com/technology/2015/feb/08/google-maps-10-anniversary-iphone-android-street-view#:~:text=A%20decade%20on%2C%20digital%20maps,to%20nipping%20to%20the%20shops.

294 Schaal, D. (2019). Google Maps Poised to Be an $11 Billion Business in 4 Years. *Skift.* https://skift.com/2019/08/30/google-maps-poised-to-be-an-11-billion-business-in-4-years/

DATE	INNOVATION	IMPACTS	ECONOMIC IMPACT	SOCIAL IMPACT	ENVIRONMENTAL IMPACT
2006	HPV vaccine for cervical cancer	Projected that cervical cancer will be eliminated as a public health risk in Australia by 2020.[295] Over 200 million doses have been distributed in 130 countries.[296] The global HPV vaccine market was valued at approximately USD 2 billion in 2016.[297]	✓	✓	
2007	Keepcup	Shown to produce 88% lower carbon emissions that disposable cups and has comparable reduced toxicity impact on terrestrial, marine and freshwater environments as well as humans.[298]	✓		✓
2009	Tank-bred tuna	Tank-breeding bluefish tuna aims the collapse of this species, which is considered vulnerable to extinct, and to improve economic relations with Japan.[299]	✓		✓
2009	BARLEYmax™	BARLEYmax™ has the propensity to lower rates of Type 2 diabetes, cardiovascular disease and colorectal cancer. The potential value of these improved outcomes for Australians from widespread, regular consumption of BARLEYmax™ is estimated to be worth approximately $305 million per year. The total savings in health system costs from increased dietary fibre intake are forecast at up to $17 million per year. BARLEYmax™ also benefits grain growers, through additional earnings from guaranteed prices for barley and diversification of farm business models.[300]	✓	✓	
2012	Hendra virus vaccine	Through collaboration between CSIRO and overseas organisations, the vaccine developed is the most effective way of reducing the risk of Hendra virus infection in humans, a virus ranked at the same biosecurity level as Ebola. No vaccinated horse has ever contracted Hendra virus.[301]		✓	
2013	Stillbirth blood test research	Breakthrough by the University of Melbourne in discovering an accurate way to measure a baby's oxygen level in the womb.[302] Accelerated the development of a potential stillbirth blood test.		✓	
2015	Total Wellbeing Diet	Scientifically formulated diet by CSIRO that has shown to reduce body weight by an average of 5% in those who committed to the regime.[303] It is estimated that the net benefits are a maximum benefit of improved labour productivity of $5.8 million from improved health outcomes with a benefit-cost ratio of 2.5:1.[304]	✓	✓	
2015	Seabin	A product that skims solid waste from the surface of the water, designed to be installed in waters such as that of Marinas, Yacht Clubs and Ports. 860 Seabins have been installed in over 50 countries, with 911,478 kg of total waste captured.[305]		✓	

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297 Transparency Market Research. (2018). Human Papillomavirus Vaccine Market to reach US$ 3.5 Bn by 2025; Most Promising Indication to Invest in is Cervical Cancer. *GlobalNewswire.* https://www.globenewswire.com/news-release/2018/03/20/1442603/0/en/Human-Papillomavirus-Vaccine-Market-to-reach-US-3-5-Bn-by-2025-Most-Promising-Indication-to-Invest-in-is-Cervical-Cancer.html

298 Dyer, L. & Bengtsson, J. (2018*). Reusable coffee cups life cycle assessment and benchmark. Report for Keepcup.* Edge Environment. https://static.keepcup.com/reports/KeepCup%20LCA%20Report.pdf

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302 Medew, J. (2013). Researchers say a simple test could help to prevent stillbirths. *The Sydney Morning Herald*. https://www.smh.com.au/healthcare/researchers-say-a-simple-test-could-help-to-prevent-stillbirths-20131208-2yzef.html

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304 CSIRO (n.d.). *Total Wellbeing Diet: Addressing the problem of obesity and overweight in Australia.* https://www.csiro.au/en/About/Our-impact/Our-impact-in-action/Health/Total-Wellbeing-Diet

305 The Seabin Project. *Our Story*. https://seabinproject.com/about-us/our-story/

Case studies

Case study on PERC Solar Cells[306]

Motivation for innovation: Improve solar cell efficiency

Type of innovation: Product (passivated emitter and rear cell (PERC) silicon solar cell)

Commercialisation path: R&D in Australia, commercialisation and manufacturing through Australian-Chinese joint ventures

Impacts: 80% share of solar cell manufacturing capacity, flow-on benefits to Australia estimated over $8 billion, solar energy accounting for 8% of Australia's electricity in 2019, reduced greenhouse gas emissions and other hazardous gases

Developed in the 1980s, the passivated emitter and rear cell (PERC) silicon solar cell was the record-holder in silicon solar cell efficiency up until 2014. Led by Martin Green and his team at the University of New South Wales (UNSW), the PERC cell took silicon cell efficiencies from around 22% to 25% during their record-setting period. Commercialisation and manufacturing were dominated by Australian-Chinese joint ventures, with these pioneering businesses rapidly adopting PERC technology from 2012 onwards as the solar industry matured and its manufacturing costs fell. This technology has created significant value for Australia from energy efficiencies, reduction in greenhouse gas emissions and increased employment for rural areas.

Early oil embargos in the 1970s and the desire for energy independence catalysed a global push for solar research, especially in the US but also in Australia and other countries. Amidst the following global race to increase solar cell efficiency, the PERC silicon solar cell was first developed. The PERC silicon solar cell is a type of photovoltaic cell – a system that converts energy from sunlight directly into electricity. To improve the effectiveness of solar cells, the aim is to make them as efficient as possible. Reducing the amount of wasted energy means that the same amount of sunlight can produce more electricity. Greater energy efficiency also brings down costs, as fewer solar cells, transport, land and support structures are needed for a specific power output. Energy efficiency in the 1970s and early-1980s reached only around 17%, with the remainder being reflected or lost as heat. The PERC cell introduced a new solar cell architecture different and more energy-efficient than the standard cell because it removed defects in the silicon surface, also allowing for better capture of sunlight and better electron capture.

Led by Martin Green and his team at UNSW, the PERC technology was first documented in 1983. This new cell reported a record efficiency level of 22-23% in 1989, an improvement on the record already set by the UNSW team in 1985 of 20%. Despite this success, the cell was not then commercially viable given its more complex processing. Further developments were made by the UNSW team, and in 2008 the 25% efficiency milestone was reached. This efficiency record remained until 2014. Once again, despite the tremendous efficiency improvements, the technology was not commercially adopted until 2012 when the PERC cell began to be rapidly commercialised. The first implementation of PERC technology was reported by a Chinese business founded by Zhengzong Shi, one of Martin Green's PhD students, called Suntech Power in 2009. Manufacturing of PERC solar cells has become the commercial standard and, with the help of additional Australian technology such as advanced hydrogenation techniques, the average cell efficiency rose above 20% in 2012. This rise in cell performance, coupled with manufacturing innovation and new ancillary technology have combined to lead to price reductions of more than 90% over the last 10 years, making photovoltaic cells cheaper than conventional energy sources in most locations around the world. PERC cells have now become the industry mainstream.

Although much of the R&D for the PERC technology took place in Australia, manufacturing and commercialising the technology was not considered commercially viable in Australia. Chinese businesses had a strong comparative and competitive advantage given their lower input costs, the supply of supporting technology, and the ability to disseminate information to rapidly reach best industry practice.

PERC silicon solar cells are the current market leader for solar cells, having over 80% of silicon-based manufacturing capacity. Although recycling solar cells is still problematic, the key benefit of the technology is the environmental benefits, with solar energy accounting for over 8% of Australia's electricity in 2019. This could lead to a reduction of 5% in greenhouse gas emissions by the mid-2020s.

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The flow-on benefits to Australia are estimated at over $8 billion. The realisation of value of shareholdings and options held by Australians in the Chinese solar cell manufacturing businesses has contributed $1.4 billion to national wealth in Australia, with an additional $1.5 billion due to GST and tax payments. Relief from unemployment benefits as a result of over 25,000 being employed for solar installations are estimated at $0.4 billion. This employment has been spread across the country, providing significant rural employment opportunities. The largest contribution has been the societal benefits arising from the technology, with the value of electricity generated minus its cost, plus reduction of carbon dioxide emissions, the health benefits of other avoided harmful emissions such as sulphur dioxide and from reduced electricity distribution losses amounting to between $5.5 billion and $11.8 billion. Finally, the reduced costs of installing PERC systems due to smaller required area is predicted at $0.75 billion from 2018 to 2028.

Case study on Google Maps[307]

Motivation for innovation: To improve the functionality and accessibility of online mapping services

Type of innovation: Product (Web browser and mobile application)

Commercialisation path: Programmed and developed by Australian start-up, acquired by Google to further develop and commercialise

Impacts: Most popular smartphone application in the world, accounts for 13% of all internet searches, estimated to earn USD 4.86 billion this year and predicted to earn USD 11 billion in 2023

Google Maps is a web mapping service, providing information about geographical sites and locations across the globe. In addition to road maps, Google Maps provides detailed satellite imagery, route planning by multiple means of transport, traffic conditions, views of streets (Street View) and aerial photography. Google Maps was first conceived by Sydney-based start-up Where 2 Technologies in 2001, a Sydney-based led by Noel Gordon, Stephen Ma and brothers Lars and Jen Rasmussen. Before Google Maps, navigation routes were not overlaid on top of the map but rather a separate list of directions, which one could print off or write down. Further, earlier mapping services required special software to operate and needed constant refreshing. Google Maps, on the other hand, overlaid its directions on top of the map and operated as a Web browser, improving the functionality and accessibility of mapping services. Google Maps initially began as an application called Expedition and was built from 2001 to 2003. To fund the technology, Where 2 Technologies began looking to secure funding and in 2004 was acquired by Google for an undisclosed amount, and the team was employed by Google to continue developing the technology internally. The technology was redesigned to be an online platform rather than an application and was subsequently launched in February 2005. All revenue from the platform is retained by Google.

Google Maps has proven to be very successful, both as a Web browser and as a downloadable application. Google Maps accounted for 13% of all internet searches in 2018. In 2017, Google announced that over 1 billion individuals actively use Google Maps. With 54% of users using Google Maps at least once, it is the most popular smartphone application in the world. The Android version has been installed over 5 billion times. Google has over 7,000 people working full-time on its online mapping service and consists of 21 million gigabytes of data. 45 million kilometres of road has been mapped by Google in over 190 countries between 2005 and 2013. Google Maps is estimated to earn USD 4.86 billion in 2020 and to grow to USD 11 billion in 2023. The global web mapping market size was estimated to be USD 8.04 billion in 2017.

The full value of spillover effects or Google Maps to other industries is hard to quantify. Geospatial services reduce travel costs thanks to route planning, help drive business sales by providing useful information and reviews, and help businesses make strategic decisions about network and store locations. In a study of 22 countries (2016), geospatial services were estimated to have indirectly generated consumer benefits of over USD 550 billion, created 4 million direct and 8 million indirect jobs, improved revenues and costs by 5% for sectors contributing 75% to global GDP, as well as numerous societal and environmental improvements through greater transport efficiency.

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Case study on Australian canola and EU market access[308]

Motivation for innovation: To secure access to EU canola markets after legislative amendments imposed additional requirements on biofuels

Type of innovation: Process (life cycle assessment of Australian canola on greenhouse gas emissions)

Commercialisation path: Early research by CSIRO, life cycle assessment undertaken by various public and private Australian organisations

Impacts: $2.5 billion of canola exported to the EU since report acceptance, robust environmental measurement techniques, enabled Australian farmers to better understand their supply chain and meet further emission reductions

The EU biofuels market is the largest market for Australian canola, particularly non-GM canola, with close to half of Australia's canola production entering the EU market between 2013 and 2018. In 2015, the EU announced that they would tighten their emissions regulations and only accept biofuels if they provide sufficient savings in greenhouse gas emissions relative to the fossil fuels they replace. Specifically, from January 2018 onwards biofuels (such as canola oil) would be required to provide a minimum 50% saving in emissions relative to fossil fuels (or 60% if plant where fuel is produced in a newly constructed plant). This EU policy required locally determined values produced by an independent science organisation instead of the default canola emissions figures previously used when calculating biofuel emissions savings. This motivated Australia to develop and apply local capability in life cycle assessment methods and produce and submit the required report on the GHG emissions of canola oil. The alternative was to risk loss of access to the EU markets (in the event of non-approval) or the loss of at least one season of exports (in the event of late implementation).

A local independent report on GHG emissions was required under the legislation, showing that Australian canola met the emissions requirement. CSIRO was called upon by the Australian Oilseed Federation (AOF) and the Australian Export Grains Innovation Centre (AEGIC) to address the issue. Drawing on their deep background knowledge in agricultural Life Cycle Inventory, their multidisciplinary capacities, their access to resources and their ability to coordinate with several players to ensure successful execution, the CSIRO was able to produce a Country Report for Australian canola within the desired timeframe. This report demonstrated that Australia canola, when factoring in post-farmgate emissions, was below the EU GHG savings target. The report was subsequently accepted in December 2017, making Australia the first country to have a report submitted and accepted.

The early work underpinning the report in developing the Life Cycle Inventory of Australian agriculture was led by Dr Sandra Eady of CSIRO in partnership with Tim Grant of LifeCycles. Using this knowledge, CSIRO worked with subcontractors Lifecycles and Meo Carbon to undertake a life cycle assessment of Australian canola. This preliminary assessment was then externally reviewed by the University of Melbourne and international collaborators to ensure the canola GHG emissions were sufficiently close to warrant the investment in a full report. The feedback provided was integrated into the final report submitted to the EU. Collaboration between the CSIRO, AOF, AEGIC, DFAT and the Australian embassy in the EU ensured all information requests were promptly granted and the expedited the assessment of the Country Report.

The main impact of CSIRO's work was the securing of canola export access to the EU market. Since the report was accepted to mid-2019, the value of canola exported to the EU exceeded $2.5 billion. Additionally, the premium paid on non-GM canola further improved the profitability of Australian grain traders. The report acceptance also helped prevent market disruption and extreme competition in other global canola markets. Furthermore, the work and collaboration has led to a greater understanding of the Australian grain sector and developed a robust life cycle assessment framework for other grains that allows Australia to meet new sustainability demands of the sector. A flow-on benefit of this was the ability for farmers to better understand and improve their supply chain and enabled targets for further reduction of emissions. The work strengthened relationships with the EU and the global collaboration provided a precedent for further multi-national engagement.

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Case study on polymer banknotes[309]

Motivation for innovation: To improve the security of Australian banknotes

Type of innovation: Product (polymer banknotes incorporating Diffractive Optically Variable Devices (DOVDs))

Commercialisation path: R&D by CSIRO and Australian universities, commercialisation through public-private partnership with the RBA

Impacts: Savings of over $1 billion, reduced counterfeiting and expedited verification, more environmentally friendly, less disease/bacteria transmission, over 50 countries adopting polymer banknotes

Polymer banknotes are notes made from synthetic polymers and were fully issued in Australia from 1992 to 1996. Led by CSIRO, the banknotes were developed through the 1970s and 1980s, and the technology was commercialised through a joint venture between the Reserve Bank of Australia and Innovia Films. Financially, polymer banknotes have saved the Reserve Bank over $1 billion, and are also more environmentally friendly, less prone to counterfeit and more hygienic than their paper counterparts.

In 1966, when Australia converted from the Imperial system to a decimal currency, the paper banknotes were considered to have state-of-the-art security features to prevent forgery; they were watermarked, threaded with metal, and used raised print (intaglio). In one year, however, high-quality forgeries of the $10 note were found circulating. To resolve this counterfeiting threat, new polymer technology was devised to improve the banknotes' security. These innovative banknotes were made from a synthetic polymer and incorporate security features not available on ordinary paper banknotes. Principally, the notes incorporated devices so they could not be photographed. These devices, called Diffractive Optically Variable Devices (DOVDs), change in appearance when the external environment is changed, such as temperature, pressure and angle of viewing. The smooth synthetic polymer film of the bank notes improved the effectiveness of the DOVDs and made it more difficult to counterfeit as no commercially available alternative was available at the time of production. These innovations made modern polymer banknotes practically impossible to forge.

The inception of the idea of polymer banknotes came about through the arrangement of a 'think-tank' in 1968, comprising the CSIRO, the Reserve Bank of Australia and several Australian universities. With CSIRO leading the development, particularly research scientist Dave Solomon, the banknotes and the affiliated technology were developed in secret during the 1970s and 1980s, with 50 million banknotes produced to prove the practicality of polymer banknotes. The notes were tested for field performance and eventually were released as a limited edition $10 note for the Bicentennial year in 1988. By 1996, all issued Australian banknotes were polymer making Australia the first country to adopt polymer-based notes. Though there was

Though there was some initial disagreement surrounding commercialisation between wanting to offer the technology for free to world banks and wanting to capture the commercial value of the technology, the latter position was accepted, and the technology was eventually offered to other world banks at a commercial rate. The RBA, in a joint venture with Innovia Films, formed Securency International Pty Ltd and marketed and exported the notes globally. Currently, Securency exports to 25 countries. The banknotes are produced by Note Printing Australia (NPA), which since 1998 has been a wholly owned subsidiary of the RBA. Although there have been challenges in exporting the notes globally, with Securency and NPA both pleading guilty to conspiring to commit foreign bribery, the notes are currently exported to 25 countries.

The adoption of polymer banknotes over paper notes is estimated to save more than $20 million per year. Over the entire 25-year period, a cost-benefit analysis shows that estimated savings for the Reserve Bank of Australia and, by implication, Australian taxpayers, totals over $1 billion. These savings are attributed predominantly to the longer lifespan of the notes, reducing transport, processing, destruction and production costs over time. Outsourcing distribution in Australia to the private sector (banknotes are owned by the RBA but are distributed by cash-in-transit businesses from commercial cash depots) and the seigniorage income received by the Australian Government further contributed to the economic benefits of polymer notes. Polymer banknotes also reduced counterfeiting and expedited verification; however, these benefits, though expected to be substantial, have yet to be quantified. Polymer-based banknotes are also more environmentally friendly than paper notes. The increased lifespan of the notes results in significantly less waste

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and destruction, and the notes are more easily recycled than paper notes as they do not get worn out. Compared to paper notes, polymer notes have a significantly lower risk of passing on many diseases or hosting various bacteria and viruses. This is because the polymer can be cleaned much easier and is resistant to dirt and moisture. This impact has extended globally, with more than 50 countries (including those using Australian-made polymer notes plus others using polymer notes produced elsewhere) benefitting from the economic, health and environmental advantages of polymer banknotes.

Case study on cochlear implants[310]

Motivation for innovation: To provide a solution for hearing loss

Type of innovation: Product (hearing implant)

Commercialisation path: Traditional R&D, Australian and Chinese manufacturing operations

Impacts: 600,000 implants worldwide (250,000 from Australian-derived technology) with significant quality of life improvements, annual revenue of $1.24 billion, global workforce of 3,500

Cochlear implants have been tremendously successful commercially and have improved the lives of many individuals. The cochlear implant was invented by Dr Graeme Clark and then developed and commercialised through joint industry, research and government efforts. It remains the most widely used implant system. The Australian business that commercialised the implants, Cochlear Ltd, earns annual revenues of $1.24 billion and since 1982, over 250,000 people have received their implants.

The modern cochlear implant – the multi-channel cochlear implant – was invented by Dr Graeme Clark, with the first implant being performed in 1978. A cochlear implant is a medical device implanted into the cochlea which provides an altered sense of sound to those with sensorineural hearing loss. The cochlear implant (also known as the bionic ear) is comprised of two components. The external component is a speech processor which detects sounds and translates the sounds into a digital code. This code is then converted by the internal component, the implanted device, into electrical impulses which directly stimulate the auditory nerve between the inner ear and brain. This stimulation carries the impulses to the brain, which interprets it as sound and speech. Before Dr Clark's invention, cochlear implants were not effective at detecting speech as they could not differentiate between low to high frequencies. Thus, Dr Clark's multi-channel implants were developed to improve the usefulness of the technology.

Cochlear implants have been commercially successful while greatly improving the quality of life for many individuals. In 2016, it was estimated that over 600,000 individuals have received cochlear implants worldwide, with Dr Clark's model being the most widely used implant system. These implants have been shown to improve quality of life by 0.23 points per year (on a scale of 0 to 1). Cochlear Limited, an Australian business formed to commercialise the multi-channel implant, holds two-thirds of the hearing implant market globally, has a market capitalisation of over $12 billion and had annual revenue of $1.24 billion in 2017. Since Cochlear Ltd was formed in 1982, over 250,000 people have received their implants.

Cochlear implants also have an interesting commercialisation story. Initially, funds needed to prototype the technology were generated from a television fundraising event on Channel 10. The first implantation on a human patient convinced the government to assist in commercialising the technology in 1978. A three-way partnership was formed where researchers at the University of Melbourne provided the scientific knowledge and understanding, the Federal government provided financing, and a medical equipment exporter called Nucleus manufactured and sold the equipment. This led to the creation of many businesses selling the implants, the most prominent being Cochlear Ltd of Australia. Up until 2006, Dr Clark received an inventor's share of royalties from Cochlear Ltd. Now, only privately-owned businesses, such as Cochlear Ltd, Medel and Advanced Bionics, earn the revenue from the technology.

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Appendix E: The productivity paradox

The productivity paradox refers to the slowdown in productivity globally despite the rapid development of information technologies and computers.[311] The average growth in MFP of countries in the OECD has fallen from 1.3% in 1985-99 to 0.4% in 2000-17.[312] Like other OECD countries, Australia's MFP growth slowed in recent years.

According to McKinsey Global Institute's 2018 report *Solving the Productivity Puzzle*, two waves have dragged down productivity growth by 1.9 percentage points on average across countries since the mid-2000s.[313] The first wave involved the waning of a boom that began in the 1990s with the first ICT revolution, together with a subsequent phase of restructuring and offshoring, and this reduced productivity growth by about one percentage point.[314] The second wave involved the global financial crisis after-effects, including persistent weak demand and uncertainty, which reduced productivity growth, as investment was low even when hiring returned.[315]

Several other hypotheses try to explain the disconnect between innovation and productivity:[316]

False hopes: Inventor, investor or media-generated optimism may create a disconnect between expected versus actual impact. For example, while significant reductions in the error rate of algorithmic image recognition reflects progress in machine learning and artificial intelligence, the potential for broad commercial applications remains a niche in the short term.[317] Some suggest that digital technologies have not produced the same impacts as breakthroughs such as vaccines, clean water, telephones and cars.[318]

Concentrated distribution of benefits: The benefits from certain innovations are sometimes concentrated in small fractions of the economy without increasing total output, for instance among large businesses while most businesses (which are smaller) do not see these benefits.[319] In other words, these innovations may rearrange the shares of the pie without making it any bigger. For example, frontier businesses with exclusive technologies may gain competitive advantage and market share, and at the long-run expense of consumers.[320]

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Adoption, diffusion and implementation lag: It can take a long time to fully capture the benefits of technologies since adoption and implementation involves some combination of development, learning, restructure and complementary investments.[321] Prior general-purpose technologies, such as electrification, cars, semiconductors and the internet, took several decades before significant global value creation. General-purpose technologies such as these may at least temporarily decrease productivity due to the cost of replacing prior technologies, retraining, the costs and the time needed to implement new systems and infrastructure.[322] The contribution of technological innovation to economic growth and productivity is only realised once new technologies are widely diffused, adopted and implemented; barriers to innovation that have been flagged in the preceding chapters.[323]

Market entry, competitiveness and insolvency rates: The productivity dividend from technology adoption and wider innovation is influenced by businesses' competitive environment and the dynamism of markets.[324] Several studies find that the productivity and profits-based returns of innovation activity initially rise with reduced competition, but that these decline once the market becomes a winner-takes-all kind, and the vast majority of businesses become laggards.[325] With low competition and high barriers to entry, protected businesses within the industry may not be incentivised to generate the same economic gains.[326] Meanwhile, the OECD has suggested that this combination of low business entry and insolvency rates may enable less productive businesses ("zombie businesses") to survive, and contribute to aggregate productivity weakness due to suboptimal capital allocation and technology diffusion.[327] Australia's business insolvency rates have also fallen during this period, from around 500 insolvencies per 100,000 businesses in 2001 to about 300 per 100,000 businesses in 2018.[328] Overall, it is clear that resilient, agile businesses and competitive markets are fundamental to capturing productivity benefits from innovation.

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Dr Katherine Wynn, Lead Economist
+61 4 1236 4696
katherine.wynn@csiro.au
csiro.au/en/Showcase/CSIRO-Futures

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