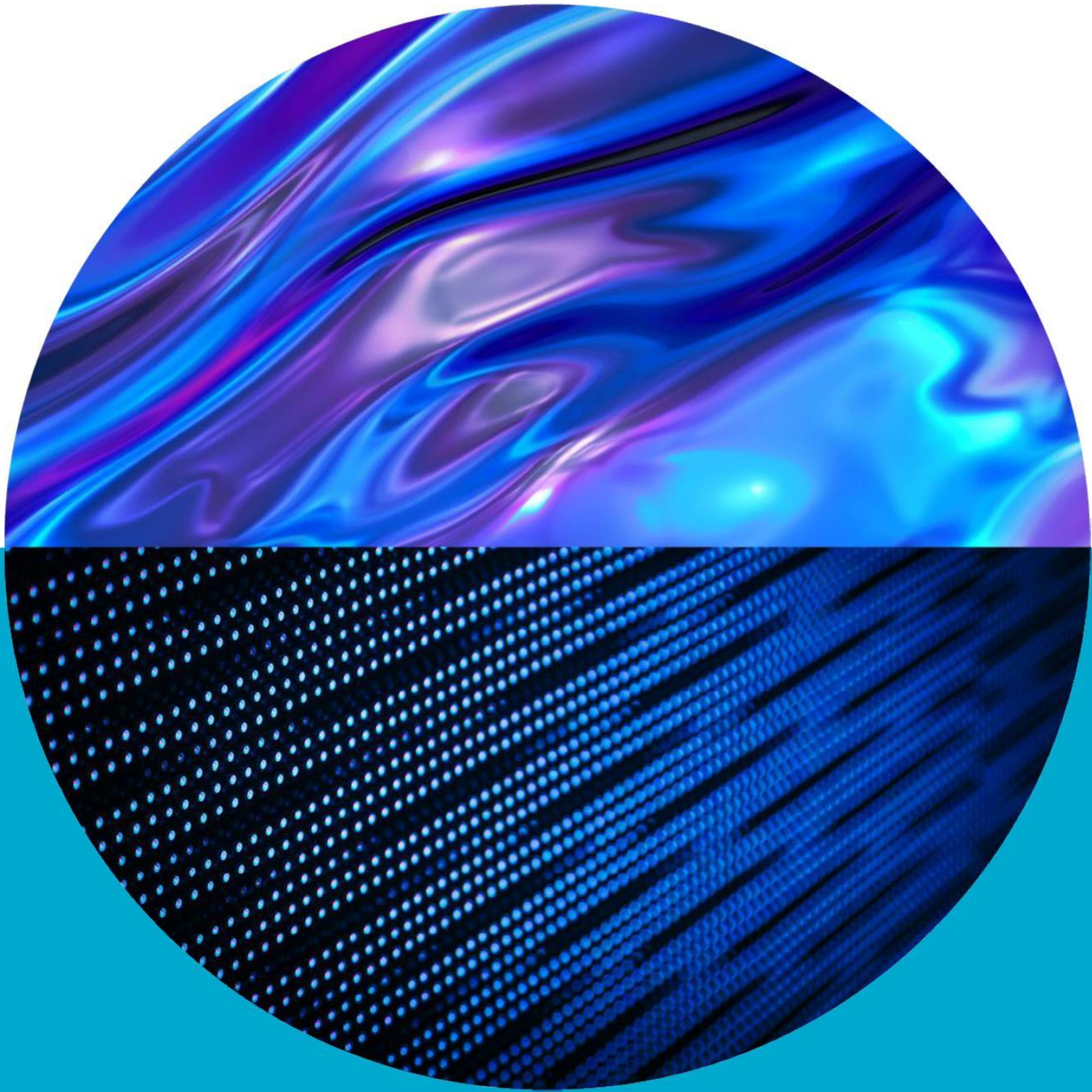
Australia's National
Science Agency

Quantifying Australia's returns to innovation

Working paper – November 2021



Citation and authorship

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Contents

Charts, figures, and tables

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We thank the following stakeholders who provided their valuable insights during the development of this working paper:

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Executive summary

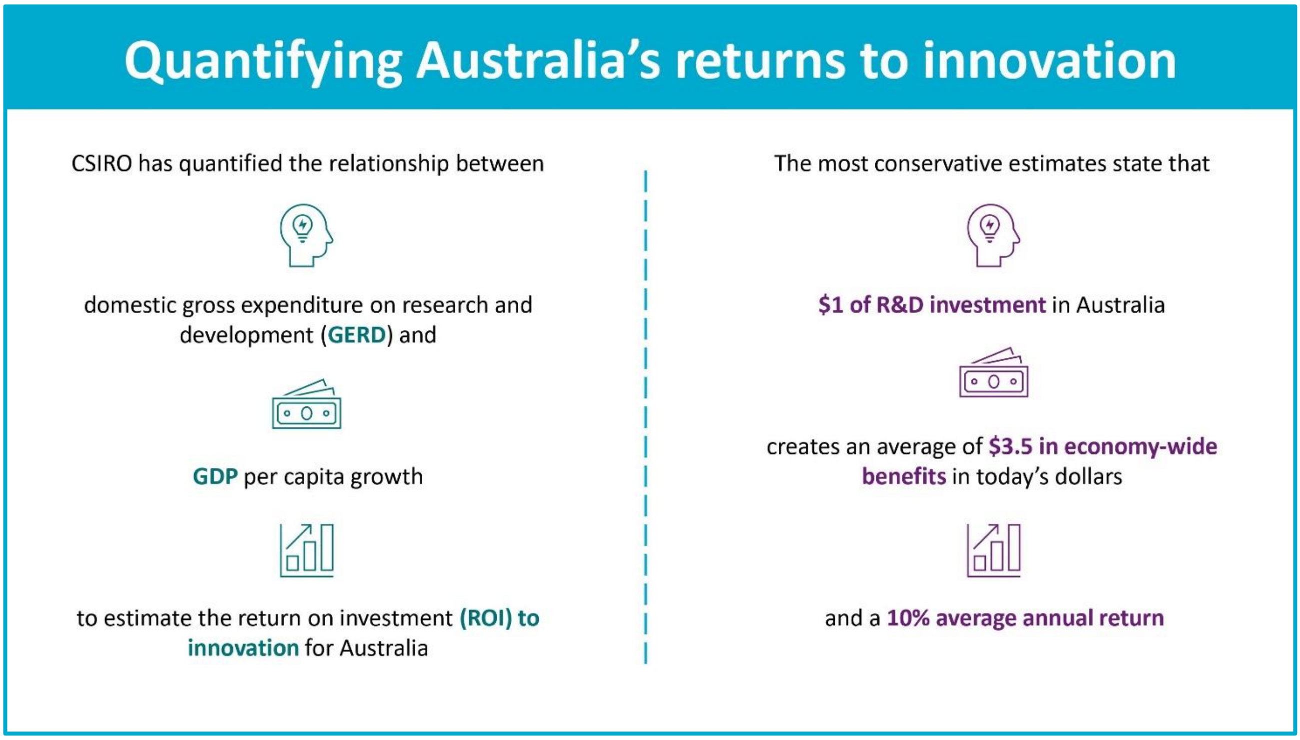
Innovation is vital to driving Australia's economy

The desire to quantify the relationship between innovation and Australia's economic growth is ever present. This working paper quantifies the relationship between domestic gross expenditure on research and development (R&D) and GDP per capita growth to estimate the return on investment (ROI) to innovation for Australia. It is intended to inform discussions regarding the role and value of innovation investment in the Australian economy, and to guide policy and investment decisions.

This paper adopts a novel approach to quantifying returns to innovation

The paper adopts the Jones and Summers (2020) approach to quantify the ROI of gross R&D spending for Australia. This is a novel yet simple macroeconomic approach that complements other methodologies for estimating the economic returns to innovation. It encompasses both successful and unsuccessful R&D investments and quantifies only economic benefits, excluding non-monetary societal and environmental benefits.

Although economic growth is entirely attributable to technological innovation in our model, two adjustments have been identified that better reflect the timing and way in which R&D is incorporated into the economy. These adjustments involve a delay between R&D and payoffs and the costs of building R&D into new capital inputs (known as embodied capital deepening).



$1 of R&D investment creates an average of $3.5 in benefits for Australia

The most conservative estimates incorporate these adjustments and state that $1 of R&D investment creates an average of **$3.5 in economy-wide benefits** for Australia in today's dollars, and a **10% average annual return**.

Removing these two adjustments yields the upper-bound for this paper's returns to innovation estimates. This unadjusted result, which does not account for the additional time and costs associated with integrating R&D into the economy, is estimated as creating **$20.8 in economy-wide benefits** and a **104% average annual return** for every dollar spent on R&D in Australia.

Key results for Australia	Average economy-wide benefit-cost ratio	Average economy-wide rate of return
Baseline results Unadjusted for delays and capital costs of integrating R&D.	20.8	104%
Delay in R&D benefits realisation Incorporates a 15-year lag between R&D investments and payoffs.	12.7	15%
Embodied capital deepening Assumes R&D must be built into new capital inputs.	4.9	24%
Combined adjustment Delay in R&D benefits realisation (10-year lag) and embodied capital deepening.	**3.5**	**10%**

R&D investment made to-date has been well worthwhile

Even with the conservative estimates (combined adjustment), the returns to innovation remain high compared to private investment returns. Historically in Australia, 10-year government bond returns have averaged under 7% per year and private equity market returns have averaged around 10% per year. Likewise, the conservative benefit-cost ratio estimate of $1 to $3.5 is notable since benefit-cost ratios greater than $1 to $1 typically indicate that a project or program has economic merit.

These findings imply that innovation investment made to-date has been well worthwhile and increasing future investment could capture substantial economy-wide returns. This is notable since Australia's R&D expenditure share of GDP lags behind the OECD average and has been decreasing over the past decade.

Further research may investigate how much economy-wide returns rise if Australia was to increase its R&D expenditure share of GDP, such as up to the OECD average. Future studies may also quantify how international R&D expenditure and activity affects Australian productivity and growth, irrespective of domestic innovation investments which are the focus of this paper.

1 Introduction

1.1 Context of this working paper

In September 2020, Benjamin F. Jones and Lawrence H. Summers at the National Bureau of Economic Research (NBER) released a working paper, 'A calculation of the social returns to innovation', which provides a novel methodology for estimating the economy-wide returns to investments in innovation and applies this to the United States. The general finding is that the average economy-wide returns for the US appear to be very large, even under conservative assumptions.

Motivated by public and private sector leaders' interest in quantifying the Australian return to innovation investment, CSIRO Futures has replicated this approach for the Australian context in this working paper. Using Australia input data, this paper adopts the Jones and Summers approach to calculate quantitative estimates of the economy-wide return on investment (ROI) of R&D spending for the Australian economy.[1]

While it is not the purpose of this paper to analyse the barriers and enablers of Australia's innovation performance,[2] it should be noted that (as seen in Chart 1.1) Australia's R&D expenditure share of GDP lags behind the OECD average. R&D performance of the OECD and most of its members (such as the US and New Zealand) has been increasing on average over time, but Australia's performance has been decreasing (along with countries such as Canada).[3] Given that over one quarter of Australia's economic output and 10% of total employment is directly related to scientific endeavour,[4] Australia's innovation performance and its ability to move towards the global innovation frontier is of national importance.

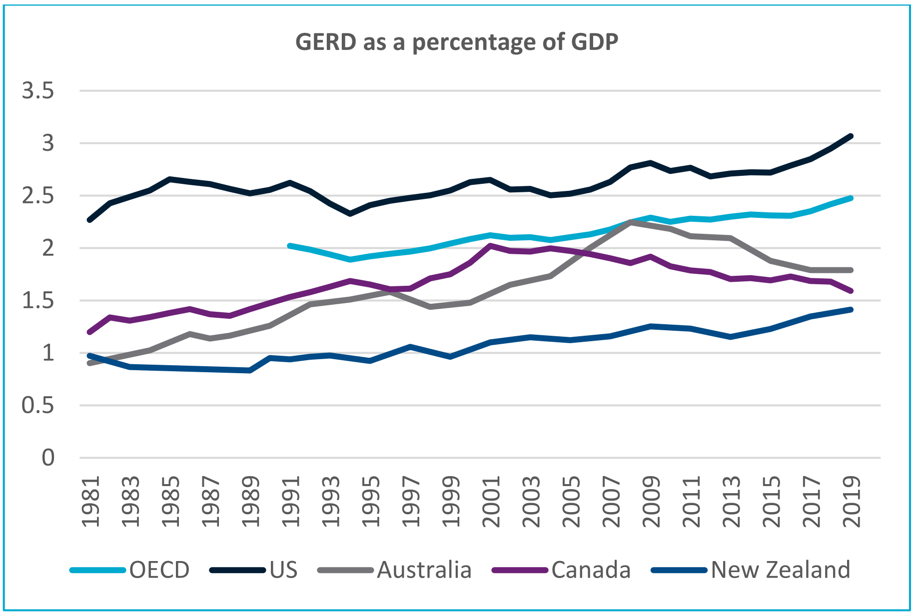
[1] Jones BF, Summers LH (2020) A calculation of the social returns to innovation. National Bureau of Economic Research, working paper 27863, accessed 3 May 2021.

[2] See upcoming CSIRO-BCA report on innovation for large companies; CSIRO (2021b) SME enablers and barriers to research, accessed 6 July 2021.

[3] OECD (2021c) Main science and technology indicators, GERD as a percentage of GDP, accessed 12 October 2021.

[4] Centre for International Economics (2016) The importance of advanced physical and mathematical sciences to the Australian economy. Report prepared for the Office of the Chief Scientist and the Australian Academy of Science, accessed 9 July 2021.

Chart 1.1: Country comparison of GERD as a percentage of GDP



Source: OECD 2021c

Along with model development and analysis to calculate economy-wide returns to innovation, an extensive stakeholder consultation process was held.

The audience for this paper is senior decision makers in the Australian government. The paper is intended to inform discussions regarding the high economy-wide benefits for Australia from R&D investment, and to guide policy and investment decisions.

1.2 Literature review

Endogenous growth theory

For decades, economists have recognised that innovation plays an important role in driving long-run economic growth. Following the work of Romer[5] – along with other innovation-based growth theories such as 'Schumpeterian' theory[6] – endogenous growth theory remains dominant in contemporary economic growth literature. This theory states that long-term economic growth in advanced economies is attributable to productivity growth which spurs technological change. Technological change arises from intentional innovation investments made by forward-looking, profit-maximising agents, where research projects exchange current costs for a stream of higher future benefits.[7]

[5] Romer PM (1986) Increasing returns and long-run growth. *The Journal of Political Economy*, 94(5), 1002–1037. Romer PM (1990) Endogenous technological change. *The Journal of Political Economy*, 98(5), 71–102.

[6] Aghion P, Howitt P (1992) A model of growth through creative destruction. *Econometrica*, 60(2), 323–51. Grossman GM, Helpman E (1991) *Innovation and growth in the global economy*. MIT Press, Cambridge, MA.

[7] Romer (1990).

In this model, knowledge is an input in production that has increasing marginal productivity, so there are increasing returns to research.[8] This means that doubling both human capital (attributes of labour that increase individual productive capability) and the stock of knowledge increases the marginal product of human capital in research. As a result, a permanent increase in human capital leads to a more than proportional increase in the amount of human capital devoted toward research.[9]

Technology is viewed as a set of instructions for combining capital, labour, and human capital into output goods. Developing new and better instructions is equivalent to incurring a fixed cost that can continue to be used at no additional cost.[10] As new technology can be used by many, it is said to be a non-rivalrous public good whereby one person's consumption does not prevent another's. Although intellectual property rights, such as patents, are used to incentivise profit-maximising agents to innovate, there will always remain technology benefits and new knowledge that cannot perfectly be kept secret and that 'spillover' to agents who do not incur the costs of innovation.[11] These positive innovation spillovers (also known as positive externalities) result in too little human capital being devoted toward R&D.[12] Each firm will choose to acquire less than the socially optimal amount of knowledge as they are unable to capture all benefits of innovation investment. Thus, any government intervention that shifts the allocation of current goods away from consumption and toward R&D will be welfare-improving.[13] In addition, integration into world markets will increase economic growth by facilitating the domestic capture of international innovation spillovers.[14]

Existing methodologies to quantify the returns to innovation

Numerous empirical estimates have been made of the magnitude of the relationship between R&D and increases in productivity and economic growth. These estimates adopt a range of approaches, including:

- **Case studies of specific technologies** and the societal benefits from their development.
- **Firm/industry-specific regression analysis** to link the commercial performance of particular firms/industries with R&D performed by themselves and by other firms or industries.
- **National-level regression methods** that examine how national productivity gains are associated with aggregate R&D investment, including from international R&D spillovers.
- **Macroeconomic growth models** that estimate the economy-wide returns to R&D under various assumptions regarding parameter values and (relatively complex) functional forms.

Each of these approaches have generated at least some studies that have found a high economic return to R&D investment.

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[8] Romer (1986).
[9] Romer (1990).
[10] Romer (1990).
[11] Romer (1986); Romer (1990).
[12] Romer (1990).
[13] Romer (1986).
[14] Romer (1990).

Case study approach

A common approach for estimating the returns to innovation are case studies of specific R&D projects and programs because they are a relatively simple way to demonstrate the benefits and need for continues R&D investment. For example, in Australia, CSIRO regularly publishes an assessment of its impact and value delivered to the economy and innovation system. Using a case study approach, the 2020 *Value of CSIRO* report found that compared with the costs of its projects and programs, the monetised impact of its work resulted in a 7.6 to 1 benefit-cost ratio, meaning that every $1 invested resulted in approximately $7.6 in economic, social, and environmental value.[15]

However, the case study approach provides only a snapshot of the entire suite of R&D activities in the economy, and it can be difficult to extrapolate from the case study results. Also, as noted by Jones and Summers, the case study approach can overstate the average returns to R&D given the case studies usually focus only on successful research projects and overlook the many unsuccessful research projects and programs that have also been invested in.[16]

Firm/industry-specific regression approach

In comparison to discrete case studies, microeconomic studies at a firm or industry level can provide a broader view of R&D returns conducted by a specific segment of the economy. These studies examine how innovation investments conducted by a firm/industry are linked to the productivity they experience, as well as potentially the spillover productivity gains of other firms/industries. For example, Bakhtiari and Breunig[17] examine the role of spillovers in R&D expenditure in Australian industries and finds the existence of positive effects on R&D spillovers between firms, particularly those that are geographically proximate.

These firm/industry-specific regression approaches can provide useful insights on the returns to R&D in a particular segment of the economy, though they are not intended for broader extrapolation to national-level innovation activity. Furthermore, these regression methods tend to have complex methodologies and can face challenges related to identifying spillovers, casual identification, and interpretation of results.

National-level regression approach

There is also extensive econometric literature on the private and public returns to R&D at the national economy level. For example, in the Australian context, the Productivity Commission has conducted econometric modelling to determine the relationship between R&D and productivity growth in Australia.[18] In one model, they found the spillover returns to domestic R&D averaging 50%

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[15] CSIRO (2021a) Assessment of CSIRO Impact and Value 2020, accessed 9 July 2021.
[16] Jones, Summers (2020).
[17] Bakhtiari S, Breunig R (2017) The role of spillovers in research and development expenditure in Australian industries. Department of Industry, Science, Energy and Resources Research Paper 2/2017, accessed 9 July 2021.
[18] Shanks S, Zheng S (2006) Econometric modelling of R&D and Australia's productivity. Productivity Commission Staff Working Paper, accessed 9 July 2021.

but conclude that empirical estimates of the effects of R&D on Australian productivity are unreliable.

However, as with firm/industry-specific regression approaches, a national-level regression approach can face several empirical methodological challenges. As noted by the Productivity Commission, issues include R&D affecting productivity through complex causal pathways, as well as issues surrounding data availability, measurement errors, potentially long delays of R&D benefits realisation, and difficulties in controlling for other factors that affect national-level productivity.[19]

Macroeconomic growth approach

Model-driven macroeconomic growth models assume various (often fairly complex) macroeconomic functional forms and their parametric values to calculate the returns to additional R&D spending. One of the early studies to do this include Jones and Williams[20] who linked theoretical models of growth theory to the empirical results in the productivity literature.

Additionally, macroeconomic growth modelling provides the basis for studies that use computable general equilibrium (CGE) modelling to estimate the returns to R&D. These studies treat R&D activity as a positive ‘productivity shock’ in a CGE model and derive estimated GDP impacts. For example, using the CIE-REGIONS CGE model, the Centre for International Economics[21] estimated that advanced physical and mathematical sciences, both directly and indirectly, accounted for 22.5% of Australian economic activity (or around $292 billion per year).

An important consideration with these studies is that judgement is required regarding the magnitude of productivity shock entered into the model. Forming this judgment can be challenging, particularly for new and emerging technologies or technologies that could disrupt existing industries and/or create new industries. Moreover, the data requirements of more complex models can be substantial, with uncertainty over parameters and other functional specifications. CGE models, in particular, can be resource intensive to construct or tailor and they can require high amounts of technical effort to identify what is driving their results.

The Jones and Summers (2020) approach

The approach presented by Jones and Summers and by this paper is a novel, yet simple, macro-level approach that is intended to complement these methodologies. It draws on modern growth theory to show how average returns to innovation can be calculated by linking the total cost of innovation investments to economy-wide gains in GDP. The approach’s key advantages are that it examines the aggregate path of GDP as a result of R&D expenditure and estimates average returns; and applies individual “adjustments” to recalculate the baseline results and emphasise particular features of innovation activity (e.g. delays in benefits realisation or the role of capital expenditure).

[19] Productivity Commission (2007) Public support for science and innovation. Research Report, Productivity Commission, Canberra, accessed 9 July 2021.

[20] Jones C, Williams J (1998) Measuring the social rate of return to R&D. *Quarterly Journal of Economics*, 113(4), 119–135.

[21] Centre for International Economics (2016).

This working paper extends the Jones and Summers approach and contributes to the literature on the returns to innovation in several ways. Firstly, it is the first study to apply the Jones and Summers framework to Australian data. Secondly, it builds on the original framework by producing additional combined baseline adjustments and details the limitations of this economy-wide returns to innovation approach. Thirdly, it conducts extensive sensitivity and scenario testing for the management of risk and uncertainty. Lastly, it differs from most Australian studies which focus on returns at a narrow firm, industry, or Field of Research level by focusing instead on returns to innovation at an economy-wide level.

1.3 Working paper structure

The remainder of this working paper outlines the methodology, results, and sensitivity and scenario analysis undertaken to calculate the economy-wide returns to innovation for Australia. It is structured as follows:

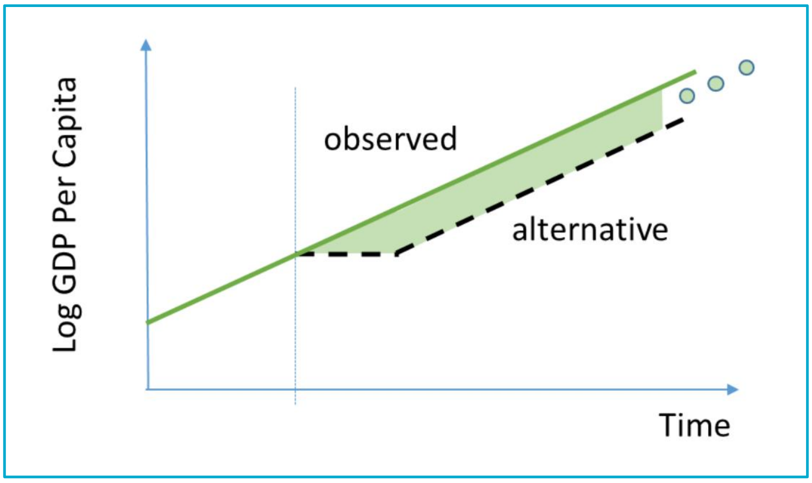
- **Chapter 2 – Methodology:** A discussion of the key assumptions, methodology, and the input figures for Australia.
- **Chapter 3 – Results and implications:** A presentation of the main results for Australia, including a discussion of its implications.
- **Chapter 4 – Sensitivity and scenario analysis:** Sensitivity and scenario analysis on the modelling results is presented, along with additional replication modelling for other similar economies.
- **Chapter 5 – Limitations and future research:** The methodological limitations and limitation of results are discussed for this approach, and areas of future research are identified.

2 Methodology

2.1 Assumptions

As discussed in Chapter 1, the primary assumption of this model is that in the long-term, Australia's economic growth is entirely attributable to growth in its total factor productivity (TFP). Jones and Summers formalise this as investing a GDP share x/y in innovation today to permanently raise productivity by g percent.[22] As conceptualised in Figure 2.1, if innovation investment was delayed one year, productivity growth would be zero for that year, then continue along the same growth path to arrive at each productivity level one year later.[23]

Figure 2.1: Counterfactual model of returns to innovation investment



Source: Jones, Summers (2020)

Romer's[24] theory of endogenous growth used implicitly in this model contains the following assumptions:

- There are increasing returns to research.
- Technology is a non-rival, partially excludable input.
- Positive innovation spillovers occur both across space and time.
- Physical capital, population size, and labour supply are held constant in the short-term.
- Anyone engaged in research has access to the entire stock of knowledge.
- The total stock of human capital in the population and the fraction of this supplied to the market is fixed.
- Aggregate knowledge accumulation achieved is consistent with firm expectations when they make production decisions.

This working paper views these assumptions as reasonable in the Australian contemporary context for the purposes of analysis.

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[22] Jones, Summers (2020).
[23] Jones, Summers (2020).
[24] Romer (1986); Romer (1990).

2.2 Estimation approach

Baseline estimates are calculated using equations that focus on the relationship between how much Australia invests in R&D, represented by its R&D expenditure as a share of GDP, and Australia's economic growth represented by its GDP growth per capita. These baseline equations for average economy-wide benefit-cost ratio and average economy-wide rate of return are the same but merely rearranged. This approach supports one saying when they invest 1 dollar in R&D in Australia, they're getting X dollars back in economy-wide benefit (as captured by GDP statistics).

As discussed further in the Limitations section, whilst R&D expenditure does not cover all innovation, it is the best available standardised measurement for innovation.

Jones and Summers outline a baseline equation with many possible adjustments,[25] whereas this working paper focuses on the high-level baseline equations, along with the adjustments of delays, capital investment and international spillovers.

Table 2.1: Baseline equations

Baseline equations from working paper	Equation	Notation
Ratio of economy-wide benefits to cost of innovation investments	$\rho = \beta \frac{g/r}{x/y}$	ρ = average economy-wide benefit-cost ratio r^* = average economy-wide rate of return β = corrective factor ($0 < \beta \leq 1$) g = GDP per capita growth rate r = discount rate x/y = gross R&D expenditure share of GDP
Economy-wide internal rate of return to innovation investments	$r^* = \frac{\beta * g}{x/y}$	

The adjustments to baseline apply individual corrections to recalculate the baseline and emphasise a particular dimension of innovation activity, adopted from Jones and Summers.[26] This assesses whether previously calculated returns may be too large or small by including other relevant dimensions that affect returns to innovation. These are:

- Delays
- Capital investment
- Combined delay and capital investment adjustment
- International spillovers – OECD

[25] Jones, Summers (2020).
[26] Jones, Summers (2020).

Table 2.2: Adjustments to baseline equations

Adjustments to baseline	Equation	Notation
Delay in R&D benefits realisation Incorporates a lag period between R&D investments and their payoffs.	$\beta_1 = e^{-(r-g)D}$	D = delay in years
Embodied capital deepening Incorporates the concept that R&D must be built into new capital inputs.	$\beta_2 = \frac{x/y}{x/y + (i_{deep} * g)}$	i_{deep} = capital stock to GDP ratio
Combined adjustment Delay in R&D benefits realisation and embodied capital deepening.	$\beta = \beta_1 * \beta_2$	
International spillovers – OECD Accounts for positive R&D spillovers from Australia to other OECD countries and vice versa.	$\rho_{OECD} = \frac{g_{OECD}/r}{(x/y)_{OECD}}$ $r^*_{OECD} = \frac{g_{OECD}}{(x/y)_{OECD}}$	

Delay in R&D benefits realisation: This incorporates a lag period between R&D investments and their payoffs. This is done because for R&D investments such as in academic research where the benefits to GDP come much later, there is a need to discount those benefits in today's terms. This adjustment assumes that R&D investments today permanently increase productivity starting D years in the future, leading to a correction to the present value of benefits, g/r.[27] D represents the delay in time until R&D use in the market peaks.[28] Other things equal, the longer the delay to benefits realisation, the lower the returns to R&D investment.[29]

Embodied capital deepening: The theory behind this is that most capital investment replaces depreciated or obsolete capital, such as needing a new car to replace one that has broken down, while a small portion of investment is capital deepening, which increases the stock of new capital that holds new ideas. Jones and Summers explore both disembodied and embodied capital deepening,[30] however the embodied story is more appropriate for Australia and for the purposes of this working paper. Disembodied capital deepening refers to productivity gains from innovation felt independently of capital investment, such as knowledge gained from reading an open access article.[31] Econometric analysis demonstrates that for developed nations in recent decades, embodied technological change explains TFP growth more than disembodied technological change does.[32]

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[27] Jones, Summers (2020).
[28] Jones, Summers (2020).
[29] Jones, Summers (2020).
[30] Jones, Summers (2020).
[31] Jones, Summers (2020) use the equation $\beta = 1 - \alpha$ where α = capital share of income to adjust the baseline for disembodied capital deepening.
[32] Krammer SMS (2014) Assessing the relative importance of multiple channels for embodied and disembodied technological spillovers. *Technological Forecasting & Social Change*, 81(1), 272-286.

Embodied capital deepening incorporates the concept that R&D must be built into new capital inputs. For example, an innovation of new computer software is only useful once built into the computer itself with a processor, monitor, plastics, metals, etc. This means that the usefulness of innovations depends on their existence within the equipment which holds them, so there is a need to account for these capital costs in calculating the economy-wide returns to innovation.

This adjustment states that the capital deepening component of investment is equivalent to the GDP per capita growth rate multiplied by the capital-output ratio, $\frac{k}{y}$. That is, $\frac{i_{deep}}{y} = \frac{k}{y} g$ where i_{deep} is the cost of investment that increases capital per worker.[33] This increases the total cost of innovation to account for both idea creation and implementation.

Combined adjustment: This has been derived by this paper as a novel extension of the Jones and Summers methodology.[34] The combined adjustment includes both delay in R&D benefits realisation and embodied capital deepening, in an attempt to provide a more realistic picture of the economy-wide returns to innovation for Australia.[35] This adjustment further reduces the economy-wide returns to innovation.

International spillovers – OECD: This looks at the returns to innovation for the OECD collectively, which implicitly accounts for positive R&D spillovers from Australia to other OECD countries and vice versa without explicitly quantifying what these returns are between specific countries. This is done because innovation in Australia brings additional spillover benefits beyond Australia's borders, and some of Australia's gains in living standards also come from innovation in other countries. Ideas spillover both directly and because ideas are embodied in traded goods and services.[36] Moreover, countries beyond the OECD also benefit from innovations within the OECD, which suggests these adjustments are conservative.[37]

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[33] Jones, Summers (2020).
[34] Jones, Summers (2020).
[35] $\rho = e^{-(r-g)D} * \frac{x/y}{x/y+(i_{deep}*g)} * \frac{g/r}{x/y}$, let $\rho = 1$, then r^* is solved from $0 = gD - rD + \ln(g) - \ln(r) - \ln(x/y + (i_{deep} * g))$
[36] Jones, Summers (2020).
[37] Jones, Summers (2020).

2.3 Input figures for Australia

Input figures were collected from the Australian Bureau of Statistics (ABS), OECD, and Jones and Summers. A timeframe of 1984–85 to 2019–20 was selected for all the variables, bracketed off primarily due to data limitations, particularly for R&D data. This timeframe aims to capture the experience of everyday Australians in recent decades.

In Tables 2.3 and 2.4, US input figures from Jones and Summers are shown on the left and for Australia on the right.[38] It is important to note that the US input figures are based on long-run averages from much of the 20th and 21st century, in contrast to the more contracted timeframe of observations for Australia. Australia has a slightly lower GDP per capita growth rate to the US of 1.7% but markedly lower R&D expenditure share of GDP of 1.6%. This is not surprisingly given the well-documented challenges Australia has in commercialising research.[39] The Jones and Summers discount rate of 5% is taken for Australia for cross-country comparison.

Table 2.3: Baseline variables

Baseline variables	Australia	Source for Australia	US (for comparison)
g **GDP per capita growth rate**	1.7%	ABS national accounts[40]	1.8%
r **Discount rate**	5%	Jones and Summers	5%
x/y **Gross R&D expenditure share of GDP**	1.6%	ABS research and experimental development data and national accounts[41]	2.7%

[38] Jones, Summers (2020).
[39] See upcoming CSIRO-BCA report on innovation for large companies; CSIRO (2021b).
[40] Australian Bureau of Statistics (2021b) 'Table 1 - Key national accounts aggregates', Series ID: A2302460K, Australian National Accounts: National Income, Expenditure and Product, accessed 12 October 2021.
[41] Australian Bureau of Statistics (1995) 'Table 1 - GERD, Australia ($m)', 8112.0 - Research and Experimental Development, All Sector Summary, Australia, 1992-93, accessed 12 October 2021.
Australian Bureau of Statistics (2010b) 'Table 1 - Gross resources devoted to R&D, summary statistics - 1992–93 to 2008–09', total expenditure on R&D, 8112.0 - Research and Experimental Development, All Sector Summary, Australia, 2008-09, accessed 12 October 2021.
Australian Bureau of Statistics (2019b) Research and Experimental Development, Businesses, Australia, ABS Website, GERD by sector 2008–09 to 2017–18, accessed 12 October 2021.
Australian Bureau of Statistics (2021a) Research and Experimental Development, Businesses, Australia, ABS Website, GERD by sector 2011–12 to 2019–20, accessed 12 October 2021.
Australian Bureau of Statistics (1994) 'Table 27 - Domestic production account - original', 5206.0 - Australian National Accounts: National Income, Expenditure and Product, Sep 1994, accessed 12 October 2021.
Australian Bureau of Statistics (2010c) 'Table 1 - Key national accounts aggregates', Series ID: A2302467A, 5206.0 - Australian National Accounts: National Income, Expenditure and Product, Jun 2010, accessed 12 October 2021.
Australian Bureau of Statistics (2019a) 'Table 1 - Key national accounts aggregates', Series ID: A2302467A, Australian National Accounts: National Income, Expenditure and Product, accessed 12 October 2021.

For the adjustment parameters, a conservative 15-year delay in R&D benefits realisation has been specified for the delay in benefits realisation adjustment. Jones and Summers estimate a 3-5 year delay for product development R&D, a 6-10 year delay for applied R&D, and a 20-30 year delay for basic R&D.[42] This paper takes Australia's shares of these R&D types and multiplies them against these delays to derive a weighted average of 15 years.[43]

For the combined adjustment, a 10-year delay has been selected instead. This is because if R&D investments necessitate the building of capital for its benefits to be realised then these benefits are likely to be realised far sooner. The key observation here is that, in the economy, it is unlikely that capital investments (which incorporate R&D-derived innovations) are being committed by investors with the expectations that economic returns will not be realised for over 10 years. Sarkar and Zhang, for example, note that long capital investment lags exceeding 10 years are not commonly observed in practice.[44] As such, the selection of a lower delay is more appropriate for the combined adjustment scenario, so this paper opts for a lower delay of 10 years.

Australia has a comparable capital stock to GDP ratio to the US. This paper cites Jones and Summers' parameters and results for the OECD which already includes Australia.

Australian Bureau of Statistics (2021c) 'Table 1 - Key national accounts aggregates', Series ID: A2302467A, Australian National Accounts: National Income, Expenditure and Product, accessed 12 October 2021.
Calculation: GERD from 1995 release divided by GDP from 1994 release (same reference year). GERD from 2010 release divided by GDP from 2010 release. GERD from 2019 release divided by GDP from 2019 release. GERD from 2021 release divided by GDP from 2021 release.

[42] Jones, Summers (2020).

[43] From 1992–93 to 2008–09, average Australian GERD consisted of 25% product development R&D, 36% applied R&D, and 40% basic R&D. Similar proportions have been found for earlier and later years.
By taking the lower bound of delays (3 years for product development R&D, 6 years for applied R&D, 20 years for basic R&D), a weighted average of around 10.8 years is calculated. By taking the upper bound of delays (5 years for product development R&D, 10 years for applied R&D, 30 years for basic R&D), a weighted average of around 16.7 years is calculated. Based on this range, this paper adopts 15 years as an approximate mid-point.
Australian Bureau of Statistics (2010a). 'Gross expenditure on R&D, by sector - by type of activity - 1992–93 to 2008–09', 8112.0 - Research and Experimental Development, All Sector Summary, Australia, 2008-09, accessed 22 September 2021.

[44] Sarkar S, Zhang C (2013) Implementation lag and the investment decision. *Economic Letters*, 119(2), 136–140.
Sarkar S, Zhang C (2015) Investment policy with time-to-build. *Journal of Banking & Finance*, 55, 142–156.

Table 2.4: Adjustments to baseline variables

Adjustments to baseline	Australia	Source for Australia	US (for comparison)
D **Delay in years**	15 years (and 10 years for combined adjustment)	Jones and Summers	3–20 years *(results shown for 15 years and 10 years)*
i_{deep} **Capital stock to GDP ratio**	3.1	ABS national accounts, capital stock data, excluding R&D capital stock[45]	3.5
	OECD	**Source for OECD**	
g_{OECD} GDP per capita growth rate	3.5%	Jones and Summers[46]	
$(x/y)_{OECD}$ Gross R&D expenditure share of GDP	2.2%	Jones and Summers[47]	

[45] Australian Bureau of Statistics (2020c). 'Table 56 - Capital stock, by type of asset', Series ID: A2422574C minus Series ID: A3346871T, Australian System of National Accounts, accessed 12 October 2021.
Australian Bureau of Statistics (2020a). 'Table 1 - Key national accounts aggregates', Series ID: A2420912W, Australian System of National Accounts, accessed 12 October 2021.
R&D capital stock is removed from the data as this would constitute double counting of R&D expenditure in the equations.
[46] Replicated with OECD (2021b) Gross national income for 2009–2017, accessed 16 June 2021.
[47] Replicated with OECD (2021a) Gross domestic spending on R&D for 1997–2018, accessed 16 June 2021.

3 Results and implications

3.1 Results for Australia

The baseline results for Australia state that $1 of R&D investment on average creates approximately $20.8 of economy-wide benefits in today's dollars. As an alternative calculation, these results also state that investment in R&D creates an average annual return of 104% for the Australian economy. It is important to note that these are the least conservative results possible under this approach (i.e. the upper-bound estimates) and do not account for the additional time and costs associated with R&D expenditure, which can only be captured with further adjustments.

The most conservative result presented below in Table 3.1 is for a combined adjustment that incorporates both embodied capital deepening and a 10-year delay. This states that for $1 of R&D investment on average creates approximately $3.5 of economy-wide benefits, or an average annual return of 10% for the whole economy.

Table 3.1: Domestic returns to innovation results

Results	Australia			US (for comparison)		
	Corrective factor (β)	Average economy-wide benefit-cost ratio (ρ)	Average economy-wide rate of return (r^*)	Corrective factor (β)	Average economy-wide benefit-cost ratio (ρ)	Average economy-wide rate of return (r^*)
Baseline results	1.00	20.8	104%	1.00	13.3	67%
Delay in R&D benefits realisation (15-year delay)	0.61	12.7	15%	0.47	6.3	13%
Embodied capital deepening[48]	0.23	4.9	24%	0.30	4.0	20%
Combined adjustment (10-year delay)[49]	0.17	3.5	10%	0.18	2.4	9%

[48] For comparison, results are calculated for disembodied capital deepening. From 1984–85 to 2019–20, Australia's capital share of income was $\alpha = 42\%$. This produces an average economy-wide benefit cost ratio of $1 to $12.1 and an average economy-wide rate of return of 61%.
Australian Bureau of Statistics (2010d) 'Table 2 - Productivity measures and growth accounting analysis', income shares - capital, Experimental Estimates of Industry Multifactor Productivity, 2008-09, accessed 12 October 2021.
Australian Bureau of Statistics (2020b). 'Table 2 - Productivity measures - market sector industries aggregate', two period average income shares - capital, Estimates of Industry Multifactor Productivity, accessed 12 October 2021.

[49] The combined adjustment results for the US were calculated specifically for this table and, unlike the other US results presented here, does not appear in the original Jones and Summers (2020) paper.

Australia has higher baseline returns to innovation than the US. One potential explanation for this is that Australia is behind the global innovation frontier, which means it will experience higher returns as it 'catches up' to the frontier (see below for a discussion of the innovation frontier). Further causal analysis is needed to determine if this explanation of results holds true.

Looking at the adjustments, Australia still has higher results than the US. The adjustments for delays, capital investment, and combined delays and capital investment all report lower economy-wide returns than Australia's baseline results. This is expected as the adjustments increase the costs of R&D investment.

Table 3.2: OECD returns to innovation results

Results	OECD		
	Corrective factor (β)	Average economy-wide benefit-cost ratio (ρ)	Average economy-wide rate of return (r^*)
Baseline results	1.00	31.8	159%

The OECD reports higher baseline returns than the Australian and US results. This is expected as it shows that positive R&D spillovers are occurring between OECD countries which increase the economy-wide returns to innovation.

Is Australia behind the global innovation frontier?

Frontier innovation refers to the first application of a new innovation, whilst catch-up innovation refers to the first application of an already existing innovation.[50] The innovation (or technology) frontier is the current outer possibility boundary an economy can achieve given its existing total factor productivity (TFP), that maximises efficiency.[51] Countries with more severe technology barriers have lower innovation frontiers as they face a more limited set of choices.[52] The global innovation frontier represents the current state of human technological knowledge, and is the 'highest' frontier of the representative country that faces no barriers.[53] The productivity growth rate of the leading country indicates growth at the frontier of knowledge, whilst productivity growth for other countries reflects at least in part the process of imitation and transmission of existing knowledge.[54] The global innovation frontier is shifted out by the introduction of new technologies.[55]

A body of empirical evidence suggests Australia is behind the global innovation (or technology) frontier. Analysis by Madsen et al. of 55 countries from 1970 to 2004 showed Australia was close to the global innovation frontier in 1970 (behind USA, Netherlands, Switzerland, New Zealand and

[50] Qureshi I (2020) Frontier vs. catch-up innovation, accessed 7 July 2021.
[51] Madsen JB, Islam R, Ang JB (2010) Catching up to the technology frontier: the dichotomy between innovation and imitation. *The Canadian Journal of Economics*, 43(4), 1389–1411.
[52] Caselli F, Coleman WJ (2006) The world technology frontier. *American Economic Review*, 96(3), 499–522.
[53] Caselli, Coleman (2006).
[54] Romer (1986).
[55] Caselli, Coleman (2006).

Canada) but average performance in proximity indicators since (TFP growth, R&D absorptive capacity, and human capital absorptive capacity) are moving Australia further from the frontier.[56] Analysis by Schmidt-Ehmcke and Zloczysti of 17 OECD countries showed Australia ranked 11th within the global technology frontier in manufacturing from 2000 to 2004, behind frontier leaders Germany, USA, and Denmark.[57] Analysis by Lafuente et al. of 45 countries from 2003 to 2013 showed that USA was at the global technology frontier during the whole analysed period, and Norway in most years.[58] In at least one of the analysed years, Australia (2003 to 2005), Chile, China and Iran sat on the frontier, while the remaining countries were behind the frontier in all years.[59] Analysis by Mastromarco and Simar of 40 countries from 1970 to 2007 showed that for the global technology frontier conditioned on human capital absorptive capacity, Australia ranked well behind the best-performing countries: Germany, Israel, and Spain.[60]

3.2 Implications of results

The primary implication of the results presented in Chapter 3 is that even when additional adjustments are applied to the baseline equation, the economy-wide returns to innovation remain high compared to private investment returns. The findings imply that innovation investment made to-date has been worthwhile and increasing future investment could capture substantial economy-wide returns. This is especially notable given the fact that Australia's R&D expenditure share of GDP lags behind the OECD average (1.6% for Australia from 1984–85 to 2019–20 compared to the OECD average of 2.2% from 1991 to 2019) and has been decreasing over the past decade (see Chart 1.1).

Furthermore, the baseline results that $1 of R&D investment in Australia creates an average of $20.8 of economy-wide benefits with an average annual return of 104% sits well within the existing Australian innovation literature and are comparable to other relevant findings.

While estimates vary significantly, these findings are also in line with the magnitude of returns found by earlier econometric studies. In a highly cited study by Coe and Helpman, the rate of return to a country's own R&D was estimated at 123% for G7 economies and 85% for the other countries, including Australia in their sample.[61] This work has been largely validated, with studies such as Kao et al. finding a rate of return to own R&D of 120% for G7 countries and 79% for other countries

[56] Madsen et al. (2010).
[57] Schmidt-Ehmcke J, Zloczysti P (2011) Industries at the world technology frontier: measuring R&D efficiency in a non-parametric DEA framework. CEPR Discussion Paper No. DP8579, accessed 7 July 2021.
[58] Lafuente E, Acs ZJ, Sanders M, Szerb L (2020) The global technology frontier: productivity growth and the relevance of Kirznerian and Schumpeterian entrepreneurship. *Small Business Economics*, 55(1), 153–178.
[59] Lafuente et al. (2020).
[60] Mastromarco C, Simar L (2021) Latent heterogeneity to evaluate the effect of human capital on world technology frontier. *Journal of Productivity Analysis*, 55(2), 71–89.
[61] Coe, DT, Helpman E (1995) International R&D spillovers. *European Economic Review*, 39(5), 859–887.

(including Australia) in their sample,[62] and van Pottelsberghe and Lichtenberg who found an own R&D rate of return of 68% for G7 countries in their sample.[63]

Even the most conservative results presented in this chapter (the combined adjustment results), which show $3.5 of economy-wide benefits with an average annual return of 10%, is a strong result. For context, the risk-free rate of return that an investor would receive on an asset with little or no risk can be proxied with the 10-year Commonwealth bond yield. For Australia, the average historical returns on 10-year government bonds from 1917–2019 is below 7%.[64] As an alternative benchmark, the average historical return on all shares in Australia is around 10%, which places this paper's most conservative result within the range of private equity market performance.[65]

Similarly, even a conservative benefit-cost ratio estimate of $3.5 is notable since a benefit-cost ratios of at least 1 indicates that an undertaking has potential economic merit. Infrastructure Australia notes that a benefit-cost ratio greater than or equal to $1 to $1 specifies that the present value of a project's benefits exceeds the present value of its costs and is used to rank projects in a budget constrained environment by which has a larger benefit-cost ratio.[66]

It should also be noted that a $1 to $3.5 average economy-wide cost-benefit ratio is smaller than more micro-level estimates, such as the 2020 *Value of CSIRO* report's calculation that every $1 invested into CSIRO resulted in approximately $7.6 in realised value.[67] However, in contrast to the 2020 *Value of CSIRO* report methodology,[68] this paper's estimates encompass both successful and unsuccessful R&D investments and quantifies only economic benefits, excluding non-monetary societal and environmental benefits. Unlike these partial studies, this paper also considers the supplementary investments that help to create the environment which facilitates uptake of new technologies.

[62] Kao C, Chiang M, Chen B (1999) International R&D spillovers: an application of estimation and inference in panel cointegration. *Oxford Bulletin of Economics and Statistics*, 61(1), 691–709.
[63] van Pottelsberghe B, Lichtenberg F (2001) Does foreign direct investment transfer technology across borders? *Review of Economics and Statistics*, 83(3), 490–497.
[64] Mathews T (2019) A history of Australian equities. Reserve Bank of Australia discussion paper, accessed 30 July 2021. It should be acknowledged that in more recent years the 10-year Commonwealth bond yield has been even lower.
[65] Mathews (2019). Further, the S&P/ASX 200, as of 30 July 2021, has experienced an annualised 10-year total return of 9.83%. See: S&P Dow Jones Indices (2021) S&P/ASX 200, accessed 30 July 2021.
[66] Infrastructure Australia (2018) Assessment Framework, accessed 17 August 2021.
[67] CSIRO (2021a).
[68] CSIRO (2021a).

Discussion: international spillovers for Australia

While the presence of spillovers between countries can be inferred (as presented in Table 3.2 with the OECD results), as noted in the Limitations section, the approach used in this paper does not quantify the size or direction of international R&D spillovers between specific countries. Starting with the work by Griliches[69], there is significant literature measuring the potential effects of external knowledge capital on an economy's productivity. For instance, estimates by Coe and Helpman imply that roughly a quarter of the benefits from R&D investments in G7 economies accrues to their trading partners.[70]

However, there is inherent complexity in the measurement of technological spillovers, and despite varied econometric approaches proposed in the literature, there is no consensus. Some studies find that foreign R&D is highly significant to Australian growth. Eaton and Kortum, for example, found that the vast majority of growth in Australia in the 1980s came from the US, Japan, and Germany, with only 8% of the growth due to domestic research activity.[71]

Yet other studies contradict this conclusion. Engelbrecht found that R&D spillovers had a mainly negative impact on domestic TFP in countries with small R&D capital stocks, including Australia, and suggested that this counterintuitive result was because lower levels of R&D capital stocks limit an economy's ability to absorb foreign R&D.[72] Likewise, a paper by Keller looked at how geographical remoteness influences technology diffusion. It found that because economies like Australia are geographically remote relative to major R&D spending economies (in this case, the G5), Australia benefits extremely little from foreign R&D.[73]

Ugur et al., in their meta-analysis of spillover-related estimates, concluded that the effect of a country's domestic R&D is double that of all international spillover types.[74] They also reaffirmed Engelbrecht's[75] suggestion that the productivity effect of spillovers is large in countries with a longer history of investment in own R&D, which builds absorptive capacity for obtaining productivity gains from international R&D spillovers.

Moreover, there is evidence that domestic R&D is what gives an economy the ability to absorb international R&D. This is effectively what much of the absorptive capacity literature argues. Scott-Kemmis et al. argued that the process of technology diffusion and absorption of external knowledge is not passive but rather, high levels of technological and managerial capability are needed to

[69] Griliches Z (1979) Issues in assessing the contribution of research and development to productivity growth. *The Bell Journal of Economics*, 10(1), 92–116.
Griliches Z (1992) The search for R&D spillovers. *Scandinavian Journal of Economics*, 94, 29–47.
[70] Coe, Helpman (1995).
[71] Eaton J, Kortum S (1996) Trade in ideas: patenting and productivity in the OECD. *Journal of International Economics*, 40(3–4), 251–278.
[72] Engelbrecht HJ (1997) International R&D spillovers, human capital and productivity in OECD economies: an empirical investigation. *European Economic Review*, 41(8), 1479–1488.
[73] Keller W (2000) Geographic localization of international technology diffusion. *American Economic* Review, 92(1), 120–142.
[74] Ugur M, Churchill SA, Luong HM (2020) What do we know about R&D spillovers and productivity? Meta-analysis evidence on heterogeneity and statistical power. *Research Policy*, 49(1), 103866.
[75] Engelbrecht HJ (1997).

identify, assess, acquire, integrate, and adapt knowledge.[76] In a large literature review, Lane et al. found that much of the literature uses investment in R&D as the main absorptive capacity measure.[77] The more a firm invests in R&D, the more it will be able to fully appreciate the value of new external information, making R&D activity one of the most important determinants of absorptive capacity.[78] So from an absorptive capacity perspective, domestic R&D may successfully capture most of the benefits that international spillovers might have for Australia.

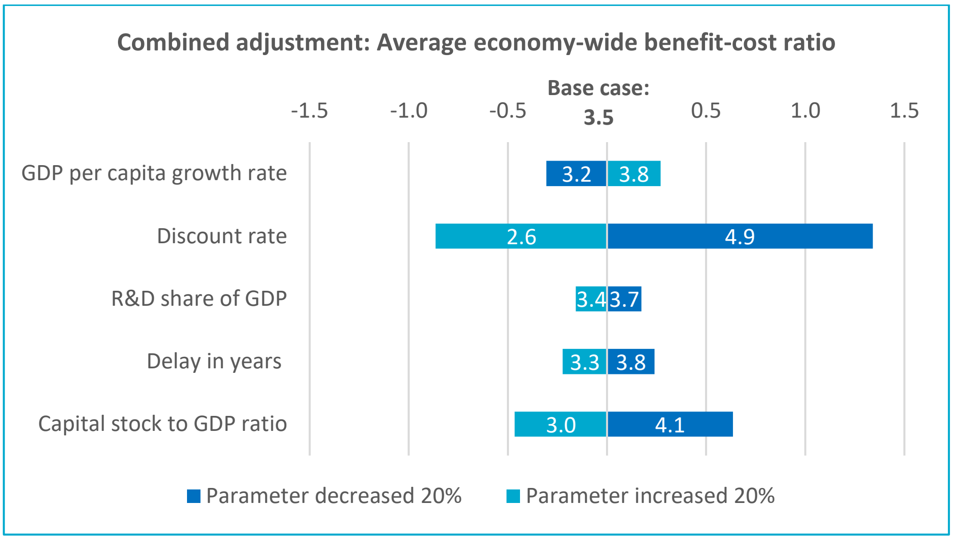
If this is the case, then the methodology presented in this paper, which directly links domestic R&D expenditure to growth in GDP per capita, remains valid since domestic R&D enables Australia to benefit from spillovers. Thus, this paper's approach may implicitly account for the role of international spillovers through its focus on only Australia's domestic R&D. Nevertheless, further research is needed to determine how international spillovers might affect Australian productivity, irrespective of domestic innovation investments.

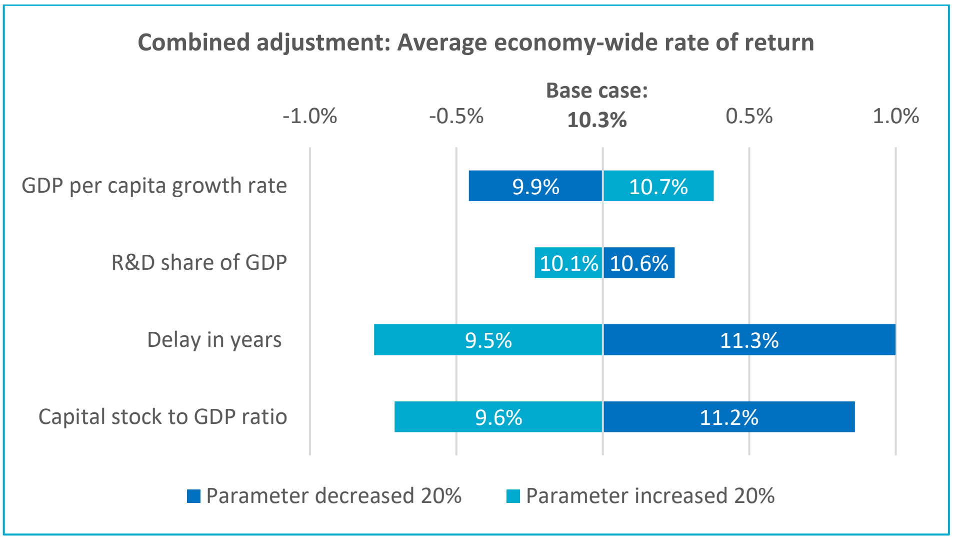
[76] Scott-Kemmis D, Jones AJ, Arnold E, Chitravas C, Sardana D (2008) Absorbing innovation by Australian enterprises: the role of absorptive capacity. Report prepared for the Department of Industry, Tourism and Resources, accessed 9 July 2021.
[77] Lane PJ, Koka BR, Pathak S (2006) The reification of absorptive capacity: a critical review and rejuvenation of the construct. *The Academy of Management Review*, 31(4), 833–863.
[78] Lane et al. (2006).

4 Sensitivity and scenario analysis

4.1 Sensitivity analysis

Chart 4.1: Sensitivity analysis for combined adjustment results





In the sensitivity analysis, model parameters were adjusted upwards and downwards by 20% to assess the sensitivity of results. As seen in Chart 4.1, the economy-wide benefit-cost ratio is most sensitive to changes in the discount rate, and the economy-wide rate of return is most sensitive to changes in the delay in years. Altering the GDP per capita growth rate increases and decreases the benefit-cost ratio by symmetric proportions (e.g. changing the GDP per capita growth rate by 20% changes the benefit-cost ratio by 0.3).

Whilst cost or time overruns are never favourable for any investment, building this uncertainty into the findings shows R&D investment is still economically viable if this occurs (see Section 3.2 for discussion of viable returns). As shown in the sensitivity analysis, if costs of R&D expenditure or delays of R&D increase by 20%, the combined adjustment results fall only from $1 to $3.5 to $1 to $3.3 and from 10.3% to 9.5% (at lowest).

4.2 Scenario analysis

In addition to the sensitivity analysis, scenario analysis was also performed on the discount rate, the delay in benefits realisation variable, and the timeframe for the input data to further examine how specifically altering inputs to a certain benchmark value (as opposed to a 20% increase/decrease range) changed the results.

Altering the discount rate

There is an open question regarding the discount rate to choose when conducting these cost-benefit calculations. While the economic literature is broad, there are generally two ways to derive discount rates for economic assessments. The first is a social rate of time preference approach (i.e. an inter-temporal discount rate approach) and the second is a social opportunity cost (SOC) of capital approach, based on a weighted average cost of capital.

Australian government guidance, including CSIRO's own impact evaluation guide,[79] tends to favour the SOC approach of around 7%, guided by the discount rate estimated by Harrison.[80] In contrast, many international guidelines tend to favour a social rate of time preference approach (between 3 to 4%).[81] There is even growing interest among some economists in a lower discount rate – for instance, a survey of academic experts in 2015 indicated that more than 75% of the respondents found a median social discount rate of 2% to be acceptable.[82]

As noted by Jones and Summers,[83] a lower discount rate will result in an even higher economy-wide return to innovation in the baseline results and in the adjusted results. But even when a higher-than-5% discount rate is chosen, the average economy-wide benefit-cost ratio is still substantial. It should also be noted that Romer himself suggests that cost-benefit calculations for research should use a social discount rate higher than the market discount rate.[84]

Table 4.1 below presents the baseline results for a discount rate of 3, 5, and 7%. While selecting a 3% discount rate significantly increases the baseline result (to $34.7 of benefit), it is also apparent from that a 7% discount rate still leads to a high average economy-wide benefit-cost ratio (to $14.9 of benefit).

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[79] CSIRO (2020) Impact evaluation guide, accessed 6 July 2021.

[80] Harrison M (2010) Valuing the future: the social discount rate in cost-benefit analysis. Visiting Researcher Paper, Productivity Commission, Canberra, accessed 6 July 2021.

[81] For example, the discount rate favoured in national cost-benefit analysis by the United Kingdom is 3.5% and for Germany it is 3%. For further discussion see 'Appendix 4: Social discount rates' in Dobes L, Leung J, Argyrous G (2016) *Social cost-benefit analysis in Australia and New Zealand: the state of current practice and what needs to be done*. ANU Press, Canberra.

[82] Drupp MA, Freeman MC, Groom B, Nesje F (2018) Discounting disentangled. *American Economic Journal: Economic Policy*, 10(4), 109–134.

[83] Jones, Summers (2020).

[84] Romer (1986).

Table 4.1: Baseline benefit-cost ratio results with altered discount rates

Discount rate	Average economy-wide benefit-cost ratio (ρ)
Baseline results $r = 3\%$	34.7
Baseline results $r = 5\%$	20.8
Baseline results $r = 7\%$	14.9

Changing the delay in years

As noted in Jones and Summers, the literature reports on a range of potential delays for different types of R&D, including a delay range of 20-30 years for basic R&D, 6-10 years for applied R&D, and 3-5 years for product development R&D.[85] While the main results in Chapter 3 opted for a delay of 15 years, the potential delay could range from approximately 11 years (if the lower delay range of 20, 6, and 3 years are chosen) to approximately 17 years (if the higher delay range of 30, 10, and 5 years are chosen).[86]

Table 4.2 below shows a range of alternative delays and their corresponding economy-wide benefit-cost ratio and rate of return results. As expected, a lower delay leads to substantially higher returns, with a delay of zero years resulting in the baseline calculation of $20.8 in economy-wide benefit and average annual returns of 104%. However, higher delays still lead to substantial returns. Increasing the delay from 15 to 20 years results in the benefit-cost ratio falling from $12.7 to only $10.8 and the annual returns from 15% to only 12%.

Table 4.2: Baseline results with altered delays

Change in delays	Corrective factor (β)	Average economy-wide benefit-cost ratio (ρ)	Average economy-wide rate of return (r^*)
Adjustment to baseline $D = 3$ **years**	0.91	18.9	37%
Adjustment to baseline $D = 5$ **years**	0.85	17.6	28%
Adjustment to baseline $D = 10$ **years**	0.72	15.0	19%
Adjustment to baseline $D = 20$ **years**	0.52	10.8	12%

When embodied capital deepening is combined with a range of delays in the novel extension introduced by this paper, the returns are noticeably lowered (as seen in Table 4.3 below). For instance, a 20-year delay with embodied capital deepening would only yield a return of $2.5 or an average rate of return of 8%. While such results are markedly lower than the results presented in

[85] Jones, Summers (2020).

[86] These figures are derived by taking Australia's shares of these R&D types and multiplying them against these delays to derive a weighted average. See Section 2.3 for further methodological discussion.

Table 4.2, an 8% return is still a strong result when placed in context of average performance on many investments currently available in private markets in Australia (see Section 3.2 for examples).

As discussed in Section 2.3, a 20-year delay is likely to be a conservative upper limit when combined with embodied capital deepening. This is because returns to R&D built into capital investments are likely to be realised far sooner. While this paper selected a 10-year delay to report the main findings for the combined adjustment, as supported by evidence on capital investment lags, further investigation is ultimately needed to determine the correct delay to use with embodied capital deepening.

Table 4.3: Baseline results with embodied capital deepening and altered delays

Combined adjustment with change in delays	Corrective factor (β)	Average economy-wide benefit-cost ratio (ρ)	Average economy-wide rate of return (r^*)
D = 3 years Embodied capital deepening	0.21	4.4	16%
D = 5 years Embodied capital deepening	0.20	4.1	14%
D = 15 years Embodied capital deepening	0.14	3.0	9%
D = 20 years Embodied capital deepening	0.12	2.5	8%

Applying a more recent timeframe for input data

In the key results, a timeframe of 1984–85 to 2019–20 was selected for all the variables. However, it is worth noting that Australia's recent economic growth experience has been unique among developed economies. From 1991 until the onset of the COVID-19 pandemic in 2020, Australia experienced nearly three decades of uninterrupted economic growth without a single recession. Some economic commentators have attributed part of this so-called 'economic miracle' to substantial policy reforms the country underwent in the 1980s and 1990s.[87]

To validate that the results from the modelling exercise remain applicable for Australia when a different timeframe is used – namely, to potentially remove the influence of policy reforms on economic growth – inputs from only 2008–09 to 2019–20 were used to recalculate the results. The input variables for the shorter and more recent timeframe are shown in Table 4.4 below.

[87] For an example of such a discussion, see Banks, G (2003) Australia's economic 'miracle'. Productivity Commission speech, accessed 6 July 2021.

Table 4.4: Australia input variables, using 2008–09 to 2019–20 timeframe

Variables	Baseline
g	0.7%
r	5%
x/y	2.0%
Variables	**Adjustments to baseline**
D	15 years
i_{deep}	3.1

The recalculation of the results with a more recent timeframe (presented in Table 4.5 below) show that the returns to innovation remain high but are nevertheless lower than when input variables from 1984–85 to 2019–20 are used for the main results. For example, the baseline results in Table 4.5 show roughly $7 average economy-wide benefit and a 33% economy-wide return in contrast to $20.8 and 105% in the main results in Table 3.1.

This appears to be entirely driven by the fact that the GDP per capita growth rate is now 0.7% as opposed to 1.7%, highlighting that the rate has declined in more recent years.[88] The remaining input variables (namely x/y and i_{deep}) do not vary much across the two different timeframes presented in Table 2.3 and 2.4, and in Table 4.4 above.

Table 4.5: Australia baseline results, using 2008–09 to 2019–20 timeframe

Results	Corrective factor (β)	Average economy-wide benefit-cost ratio (ρ)	Average economy-wide rate of return (r^*)
Baseline results	1.00	6.6	33%
Delay in R&D benefits realisation (15-year delay)	0.52	3.4	9%
Embodied capital deepening	0.49	3.2	16%
Combined adjustment (10-year delay)	0.32	2.1	8%

[88] Evidently, when looking at the past decade excluding 2019–20, the baseline results also fall by more than half as when including this datapoint.

4.3 Replication exercise

To validate the findings for Australia, the baseline returns were also calculated for New Zealand and Canada. These two countries were chosen because they have similar characteristics to Australia – namely, they are small, open high-income economies with major primary industry sectors.

The goal of this exercise is to effectively perform a 'sense check' to see whether similar economies (with roughly similar input variables) have similar returns to innovation. Overall, the baseline results for New Zealand and Canada are comparable to what has been shown for Australia and the US.

New Zealand results

The baseline result for New Zealand is that $1 of R&D investment on average creates $25.2 of economy-wide benefits and an average annual return of 126% (Table 4.7). This is comparable to the baseline Australian result of a $20.8 economy-wide benefit and 104% economy-wide returns. This is also the case with the adjusted results.

The New Zealand data was deliberately selected for comparability with the Australian timeframe, with any timeframe differences arising due to limited data availability. The 15-year delay for the delay in benefits realisation adjustment and 10-year delay for the combined adjustment were simply and deliberately chosen for comparability with the Australian results. It should be noted, however, that the shares of expenditure types (i.e., basic, applied and experimental development R&D) in Australia and New Zealand are broadly similar and the available New Zealand R&D data yields a similar weighted average delay.[89]

[89] Statistics NZ (2021) Research and development survey: 2020, accessed 2 July 2021.

Table 4.6: New Zealand input variables

Variables	Baseline	Source for New Zealand
g	1.4%	Statistics NZ national accounts and population estimates for 1983–2020[90]
r	5%	Jones and Summers
x/y	1.1%	OECD research and development statistics for 1983–2019[91]
Variables	**Adjustments to baseline**	**Source for New Zealand**
D	15 years	Jones and Summers
i_{deep}	2.8	Statistics NZ national accounts for 1987–2020[92]

Table 4.7: New Zealand returns to innovation results

Results	Corrective factor (β)	Average economy-wide benefit-cost ratio (ρ)	Average economy-wide rate of return (r^*)
Baseline results	1.00	25.2	126%
Delay in R&D benefits realisation (15-year delay)	0.58	14.6	15%
Embodied capital deepening	0.22	5.5	27%
Combined adjustment (10-year delay)	0.15	3.8	11%

Canada results

The baseline result for Canada is that $1 of R&D investment creates $14.0 of economy-wide benefits and annual returns of 70% on average (Table 4.9). As with the New Zealand results, this is broadly comparable to the baseline Australian results. The adjusted results for Canada are also of comparable size.

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90 Statistics NZ (2021) Gross domestic product: March 2021 quarter, accessed 2 July 2021.
Statistics NZ (2021) Summary figures for the NZ population, 1991-2020 (Microsoft Excel Open XML Spreadsheet, 35 KB), accessed 2 July 2021.
Statistics NZ (2021) Infoshare data on '(DISC) Estimated De Facto Population by Age and Sex (1936-95) (Annual-Dec)', accessed 2 July 2021.
91 OECD (2021a). Gross domestic spending on R&D, accessed 16 June 2021.
92 Statistics NZ (2020) National accounts (income and expenditure): year ended March 2020, accessed 2 July 2021.

The data was deliberately selected for the 1984-2020 timeframe (or close approximations thereof) to be comparable with the Australian results. Moreover, as with the New Zealand calculations, a 15-year delay for the delay in benefits realisation adjustment and 10-year delay for the combined adjustment were also chosen for comparability with the Australian results. Data on Canada R&D expenditure types (i.e., broken down in terms of basic, applied and experimental development R&D) was not readily available to allow estimation of its weighted average R&D delay.

Table 4.8: Canada input variables

Variables	Baseline	Source for Canada
g	1.2%	Statistics Canada national accounts and population estimates for 1984–2020[93]
r	5%	Jones and Summers
x/y	1.7%	Statistics Canada expenditures on research and development data for 1984-2020[94]
Variables	**Adjustments to baseline**	**Source for Canada**
D	15 years	Jones and Summers
i_{deep}	2.0	Statistics Canada flows and stocks of fixed non-residential and residential capital, 1984-2019[95]

Table 4.9: Canada returns to innovation results

Results	Corrective factor (β)	Average economy-wide benefit-cost ratio (ρ)	Average economy-wide rate of return (r^*)
Baseline results	1.00	14.0	70%
Delay in R&D benefits realisation (15-year delay)	0.56	7.9	13%
Embodied capital deepening	0.42	5.9	29%
Combined adjustment (10-year delay)	0.29	4.0	11%

[93] Statistics Canada (2021) Gross domestic product, expenditure-based, Canada, quarterly (x 1,000,000), accessed 1 October 2021.
Statistics Canada (2021) Population estimates, quarterly, accessed 1 October 2021.
[94] Statistics Canada (2021) Expenditures on research and development (R&D) by performing sector (x 1,000,000), accessed 1 October 2021.
[95] Statistics Canada (2021) Flows and stocks of fixed non-residential capital for all industries, by type of asset, provinces and territories (x 1,000,000), accessed 1 October 2021.
Statistics Canada (2021) Flows and stocks of fixed residential capital by type of asset, provincial and territorial (x 1,000,000), accessed 1 October 2021.

5 Limitations and future research

5.1 Limitations of results

While the main benefit of this macro-level approach is that it is relatively simple to understand and avoids many of the complexities inherent in other approaches, it is primarily due to its simplicity that some major limitations emerge. These limitations are categorised and discussed below under those related to the methodology and those related to the results.

Methodological limitations:

Limitation 1: Data availability

The methodology presented in this paper is constrained by the availability of Australian R&D data at a national-level gross expenditure total. As noted in Chapter 2, a timeframe of 1984–85 to 2019–20 was selected due to these data limitations. The results may change, for example, if there was access to Australian R&D data across a longer timeframe and if that data showed that the R&D expenditure share of GDP was different in that longer timeframe. Indeed, when the timeframe for Australian input variables was changed in scenario analysis to a shorter, more recent period where GDP per capita growth has been lower, the calculations showed a reduced return to innovation (see the discussion in Section 4.2 on applying a more recent timeframe).

Limitation 2: Endogenous growth assumptions

On a fundamental level, the methodology assumes economic growth is driven exclusively by innovation as per modern endogenous growth theory. However, there are competing productivity growth models in the literature that emphasise the importance of other factors to long-run economic growth. For example, Acemoglu et al. emphasise differences in economic institutions as a major driver of differences in incomes per-capita.[96] Other models and studies seek to expand on Romer's initial growth formulation, emphasising aspects such as human capital formation and the importance of international trade in influencing the innovation and growth relationship.[97]

Limitation 3: Exclusion of non-R&D innovation

Not all innovation activities are captured by available R&D statistics and so this methodology is limited in that it excludes non-R&D innovation (e.g. changes related to business management, institutional organisation, human capital, and industrial relations) and the role that they play in economic growth. For example, recent modelling suggests business investment in non-R&D innovation is at least equivalent to business expenditure on R&D.[98] However, ongoing Australian data on non-R&D innovation spending across the economy is not readily available.

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[96] Acemoglu D, Johnson S, Robinson JA (2005) Institutions as a fundamental cause of long-run growth. In *Handbook of economic growth (Vol. IA)* (Eds P Aghion, S N Durlauf) 386–472. Elsevier, Amsterdam.

[97] See for example the Uzawa-Lucas model as presented in Lucas (1988) which emphasises human capital as the key variable through which technical change occurs in the economy, or the role of international trade in economic growth in papers such as Grossman, Helpman (1989) and Rivera-Batiz, Romer (1991).

[98] Innovation and Science Australia (2020) Stimulating business investment in innovation, accessed 16 September 2021.

Limitation 4: Limited incorporation of international R&D spillovers

As discussed in detail in Section 3.2, the methodology does not quantify the size or direction of international R&D spillovers between specific countries. Should it be the case that these spillovers have a substantial impact on an economy's per capita growth experience (as some of this literature indicates), then the size and direction of these spillovers are essential in assessing the extent to which domestic R&D investment affects growth relative to external R&D. In an extreme case, an economy could face circumstances where spillovers account for the majority of productivity growth, which would severely downplay the role of domestic innovation activities.

Limitations of results:

Limitation 5: Exact magnitude and distribution of GDP increase from R&D spending

This approach does not indicate the exact magnitude of a GDP increase if R&D spending was increased by a certain amount. Unlike econometric studies which can potentially estimate the elasticity between GDP growth and R&D investment (thus indicating how a percentage increase in one might be related to the other), this study's approach is limited to measuring the average rate of return to the economy.

Moreover, because these are average economy-wide results, the results do not show how the economy-wide returns are distributed across society and exactly where these returns to R&D accrue. For instance, it does not provide insight into the extent to which private sector R&D returns are experienced as private returns as opposed to spillover benefits for broader society.

Limitation 6: Policy guidance on targeting R&D investments

This approach treats all R&D investment in aggregate and does not distinguish between R&D expenditure from different sources (e.g. public and private R&D) or directed towards different scientific and technological disciplines. As such, it cannot provide policy guidance on where R&D investments should be targeted.

Limitation 7: Non-monetary societal outcomes

Lastly, because the returns to R&D are measured in terms of GDP, the results from this approach do not measure non-monetary societal outcomes such as happiness or improved quality of life. There is significant evidence in the literature that R&D can provide a broad range of benefits that are not captured by GDP statistics, including literature around the societal benefits that arise from R&D, especially as a result of medical improvements.[99] R&D may also have positive or negative environmental outcomes. However, these additional outcomes not measured by GDP are not captured by the approach and results presented in this paper.

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[99] Jones, Summers (2020) attempt to measure the benefits that accrue from R&D via improvements in health and longevity as an extension exercise. They acknowledge the difficulty of adjusting the return calculations to reflect these benefits since this must change not only from improved health but also through a new definition of real consumption that includes the value of being alive.

5.2 Future research

Based on the discussion above, it is apparent that there are immediate areas that future research on this topic can take. Firstly, one interesting exercise would be to determine the *marginal* rate of return on innovation for Australia along with the average. That is, it is important to estimate what would happen if Australia was to increase the ratio of R&D expenditure to GDP (such as up to the OECD average) and how this may change the results presented here to increase economy-wide returns.

Secondly, future research could quantify how international spillovers and absorptive capacity affect Australian productivity and growth. While domestic R&D may capture a large portion of the effects of international spillover from an absorptive capacity perspective,[100] additional research needs to be conducted to explore the possibility of standalone international spillover effects on domestic productivity, as well as how Australia's absorptive capacity might influence these effects.

[100] For example, see Ugur et al. (2020) for empirical evidence of this effect.

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