Deloitte Access Economics

The economic contributions of Australia's research universities – the UNSW example

Final report

UNSW Australia

October 2015

Deloitte.

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Glossary

DAE	Deloitte Access Economics
ABS	Australian Bureau of Statistics
ACT	Australian Capital Territory
ADFA	Australian Defence Force Academy
ANZSCR	Australian and New Zealand Standard Research Classification
APA	Australian Postgraduate Awards
ARC	Australian Research Council
ARENA	Australian Renewable Energy Agency
ATN	Australian Technology Network
AWWA	American Water Works Association
BAA	Backing Australia's Ability
BIS	The Department for Business, Innovation & Skills
CBR	Centre for Business Research
CEO	Chief Executive Officer
CGE	Computable General equilibrium
CIE	Centre for International Economics
CMF	Continuous Microfiltration
CRC	Cooperative Research Centres
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CTO	Chief Technology Officer
DOE	Department of Energy
EBITDA	Earnings before interest, tax, depreciation and amortisation
ERA	Excellence in Research for Australia
FOR	Fields of Research
FTE	Full-time equivalent
GDP	Gross Domestic Product
GO8	Group of Eight
GOS	Gross operating surplus
GSP	Gross State Product
GW	Gigawatts
HDR	Higher Degree Research

HECS	Higher Education Contribution Scheme
HEFCE	Higher Education Funding Council for England
HERDC	Higher Education Research Data Collection
HILDA	Household, Income and Labour Dynamics in Australia
IGS	Institutional Grants Scheme
IP	Intellectual Property
IRIOM	Integrated regional input-output model
ISCED	International Standard Classification of Education
ITRPV	International Technology Roadmap for Photovoltaic
JPEG	Joint Photographic Experts Group
MCEETYA	Ministerial Council on Education, Employment, Training and Youth Affairs
MF	Microfiltration
MFP	Multifactor productivity
MIT	Massachusetts Institute of Technology
MMRF	MONASH Multi-Regional Forecasting
NASA	National Aeronautics and Space Administration
NGO	Non-governmental organisation
NHRMC	National Health and Medical Research Council
NSI	UNSW Innovations
NSW	New South Wales
OECD	The Organisation for Economic Cooperation and Development
PACEC	Public & Corporate Economic Consultants
PERC	Passivated emitter and rear cell
PERL	Passivated emitter, rear locally diffused
PV	Photovoltaics
R&D	Research and Development
REF	Research Excellence Framework
RIBG	Research Infrastructure Block Grants
ROI	Return on investment
RTS	Research Training Scheme
SDK	Software development kit
SEO	Socio-economic Objectives
TFP	Total Factor Productivity

TOA	Type of Activity
UK	United Kingdom
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNSW	University of New South Wales
US	United States
VFR	Visiting Friends and Relatives
GIS	Geographic Information Systems
PBS	Pharmaceutical Benefits Scheme
HELP	Higher Education Loan Program
SEADU	Student Equity and Disabilities Unit
IT	Information technology
ICT	Information and communications technology
KTO	Knowledge Transfer Organisation
HEFCE	Higher Education Funding Council for England
HESA	Higher Education Statistics Agency
IPO	Initial public offering
APLU	Association of Public and Land-grant Universities
CICEP	Commission on Innovation, Competitiveness, and Economic Prosperity
UV	Ultraviolet

Executive Summary

Universities contribute to the Australian economy and society in many and varied ways. Through their operations and the expenditure of their students and visitors, they contribute to economic output and employment. The core functions of universities – teaching and learning, and research discovery and adoption – build human capital and drive technological progress. This contributes to the productive capacity of the nation which helps to drive growth in living standards. While many of these contributions have been considered in isolation by previous reports, few studies have provided a comprehensive account of the contribution of universities to the Australian economy.

UNSW (The University of New South Wales) commissioned Deloitte Access Economics to undertake a comprehensive assessment of the University's economic contribution, to exemplify the significant contributions made by Australia's universities. This report provides a rigorous and replicable framework rooted in the best-available literature for assessing the economic contribution associated with the entire gamut of universities' activities. The analysis establishes the significant economic contributions made by UNSW to the economies of NSW and Australia and demonstrates the considerable benefits that Australian universities can generate for our nation.

Australian universities have a critical role in supporting knowledge-driven economic growth.

Through programs of teaching and learning, Australian universities contribute to human capital formation by training a qualified and adaptable labour force, including scientists, professionals, technicians, teachers, and future government, civil service, and business leaders.

Universities' research activities, which lead to knowledge discovery and adoption, provide crucial support for the nation's innovation system. Research contributes to technological progress through innovation and entrepreneurship, generating considerable contributions through knowledge spillovers, and creating spin-off technologies and companies.

At the same time, the norms, values, attitudes, and ethics that universities impart to students are the foundation of the social capital necessary for constructing healthy civil societies and cohesive cultures—the very bedrock of good governance and democratic political systems.

Like all research universities, UNSW plays a vital role in supporting economic growth in Australia.

UNSW's contributions to the economies of NSW and Australia can be evaluated in terms of the goods and services *demanded* by the University, its students and visitors, as well as through the outcomes *supplied* by the University (i.e. skilled graduates and research output) and their effect on the productive capacity of the economy.

Demand-side contributions

As economic entities, universities contribute to the economy through their ongoing financial operations, and the expenditure of students and visitors – providing employment and income primarily for workers and businesses in their respective states, but also other parts of Australia. This contribution is measured in terms of the value-added and can be represented as a share of Gross State or Domestic Product (GSP and GDP) and full-time-equivalent (FTE) employment.

Utilising well-established methodologies for estimating the economic contribution of university operations, students who move to the universities' local region to study and the associated visitor expenditure, it is estimated that:

- UNSW's ongoing operations, student and visitor expenditure in total contributed $1.76 billion to Australian GDP in 2014, including $1.58 billion to GSP in NSW.
    - Of this total $1.76 billion contribution to Australia, over $1.4 billion was contributed by the operations of the university itself, while around $315 million was contributed by students and associated visitors to Australia.
    - By way of comparison, this total contribution to NSW is equivalent to 7% of the total education and training industry output of the state.
- The equivalent contribution to employment was 11,700 FTE Australian jobs in 2014, including 10,500 in NSW.
- While not additive to the results above, UNSW's annual capital expenditure from 2012 to 2014 contributed $90 million on average per year to Australian GDP, including $77 million to GSP in NSW.

Supply-side contributions

Through their **teaching and learning activities** universities enhance the human capital of their students. This boosts the lifetime earnings of these **skilled graduates**, and increases the **supply** of skilled workers available to the economy, thereby lifting the productive capacity of the economy as a whole.

Utilising findings from Australian and international modelling of the *causal* effects of higher education attainment on productivity, it is estimated that:

- **university education added $140 billion to GDP in 2014**, by raising the productivity of the workforce,
- UNSW's 4,900 bachelor degree graduates from 2013 will, as a result of their university education, **contribute as much as $204 million to Australia's GDP each year over their lifetimes – equivalent to around $41,500 per graduate (each year),**
- UNSW's 8,100 bachelor and post-graduate degree graduates from 2013 will earn, in total, an **additional $56 million on average each year over their lifetimes** (before tax), compared to what they would have earned with a lower qualification.

Through its **research,** the university sector plays a major role in contributing to long-term economic growth and well-being in Australia. University research and discovery such as that conducted by UNSW **supplies knowledge** which, if adopted by industry, government and broader society, can lead to better systems, materials and products, and improved overall productivity.

The benefits of UNSW's research activity are as broad and varied as the research itself. The university sector's applied research has **clear and demonstrable impacts on productivity and economic growth**, particularly through enhancing technology. This is demonstrated by a number of research projects that have been undertaken within the UNSW's Faculty of Engineering. More exploratory and basic research discovery can also have **significant, long-term impacts on economic growth**, by adding to technological progress in the economy and enhancing the social and political discourse of the nation and its citizens.

Because of the complex nature of the economic benefits generated by university research, and the associated time-lags, it is challenging to measure the benefits in a comprehensive, reliable and meaningful way. In particular, without in-depth examinations of the return to individual research projects (for example, through case studies) it is not generally possible to accurately determine the nature, form and extent of these benefits.

This report includes an extensive review of all of the established approaches to estimating the contribution of university research. Three key approaches have been selected to underpin a comprehensive assessment of UNSW's research contributions from several levels:

- a **top-down** approach which estimates the overall contribution of university research to long-term economic growth;
- a **faculty-investment** approach which assesses the economic impacts of the current research projects being undertaken within the Faculty of Engineering; and
- a **case study** approach which considers the economic impacts of three exemplar research programs at UNSW's Faculty of Engineering.

Top-down modelling

The contribution of university research output, measured by recurrent expenditure on higher education research and development (R&D), to economic output has been estimated using an econometric model of growth across countries.

Based on this model, **the stock of technology and knowledge attributable to Australia's universities contributed approximately $160 billion to GDP in 2014, almost 10% of total GDP**. This represents the contribution of historical investments in research made by Australian universities. This contribution exceeds the entire value of Australia's mining industry, which accounted for approximately 9% of total GDP in 2014.

- UNSW's current spending on R&D represents approximately 9.4% of total R&D spending by Australian universities nationally.[1] Econometric modelling indicates UNSW's share of the total economic contributions of the stock of technology and knowledge would be in the order of $15 billion.
- Looking forward, as an illustration of the impact of research universities in Australia, it is estimated that UNSW's current annual expenditure on research and development of around **$1.04 billion**[2], if sustained over time[3], would:

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[1] Source: UNSW data provided for ABS Cat. No. 8111- Survey of Research and Experimental Development Higher Education 2012 and Barlow, The State of Research in Australian Universities, 2015, derived from ABS 8111

[2] Estimate based on above UNSW data provided for ABS Cat. No. 8111 and trend approximation of 2014 total spending on R&D nationally. See section 4.3.2 for further detail.

- increase GDP by between $106 and $190 billion over a period of 35 years, based on research expenditure of almost $17 billion (both in present value terms);[4]
- indicating a return for the economy of between $5 and $10 for each $1 invested, over a period of 35 years (in present value terms).
  - this implies the equivalent annualised return from investments in real per capita university research lies in the order of 60%-100%
  - by way of comparison, the current annualised real return to paying down government debt is around 1.5% in real terms and the historical real before-tax rate of return on private investment is around 7%.[5]
- These measured effect sizes are large, and the resulting range of estimated impacts reflects a variety of uncertainties inherent in this analysis. Nonetheless, the estimated outcomes are consistent with results from other studies both in Australia and overseas and point to **significant positive economic spillovers from university research expenditure**.

These estimates of the long-term macroeconomic impact of university research output clearly demonstrate a strong relationship between university research and economic growth. However, they reveal little of the mechanisms by which the impacts occur, or the pre-conditions necessary to ensure that such benefits are realised. As such, while they are generally applicable in the context of long-term models of economic growth, these effect sizes cannot be reliably applied generally to individual research activities for the purposes of estimating economic impacts.

Faculty investment returns – UNSW Faculty of Engineering

Drawing on the most relevant and defensible estimates from the literature, the expected annual rate of return to the economy of strategic and collaborative university research would likely be between 25% and 40% on average, should the knowledge generated by this research successfully flow through to industry end-use. By way of comparison, the historical expected rate of return on private (business) investment in Australia is estimated to be around 7% per annum. This indicates that the **gross returns to the UNSW Faculty of Engineering's 2014 research activity could be between $85 and $95 million.**

- There is a wealth of international literature on the private and social returns to investment of industry R&D and R&D undertaken by other public research institutions.
- Where basic and applied research is combined with effective knowledge exchange[6] the economic impacts of the research are likely to be similar in nature and magnitude to the returns estimated by empirical literature on industry R&D.
- UNSW's Faculty of Engineering undertakes a range of strategic research (some in collaboration with industry) and appears to have been effective in exchanging this

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[3] More specifically, sustained year-on-year in real per capita terms.

[4] Further explanation of this present value calculation is included in footnote 28 on page 54 of this report

[5] Further explanation of this result is included in paragraphs 2-3 on page 80 of this report.

[6] Where the university actively disseminates knowledge to groups such as industry, NGOs, and public bodies, through various channels such as publications, consulting and contracting, and licensing.

knowledge with various external users via several channels (e.g. as evidenced by the case studies presented in this report).

- In light of this comparability, Deloitte Access Economics identified conservative estimates of the total returns to the economy from investments in applied R&D, and applied these to the investments in the Faculty of Engineering's research projects in 2014. This may in fact lead to conservative estimates of the economic contributions of the faculty's research, as many authors conclude that the impacts from more basic, 'blue-sky', research at universities likely exceeds that observed in industry.
- In the future, developing of a set of knowledge flow/transfer metrics could provide UNSW with a deeper, more systematic understanding of where the economic (and social) impacts of its research are likely to be most significant, and where industry estimates of returns to research investments could be appropriate for monetising these economic contributions.

Case-studies – UNSW Faculty of Engineering

These university and faculty-level estimates, while informed by broader estimates of research impacts, are ultimately generated by specific research projects and activity occurring at UNSW. Indeed, the most robust and accurate way to gauge the total impact of a university's research activity is to systematically assess each of its individual research projects individually and in detail. Naturally, such a task would be infeasible at a university such as UNSW given the large number, variety and complexity of its research programs.

To demonstrate the impact that individual research projects can have on the economy and broader society, three exemplar research programs at the UNSW Faculty of Engineering were analysed in detail. These projects demonstrate the existence of highly significant economic and social returns resulting from UNSW research over a long period of time:

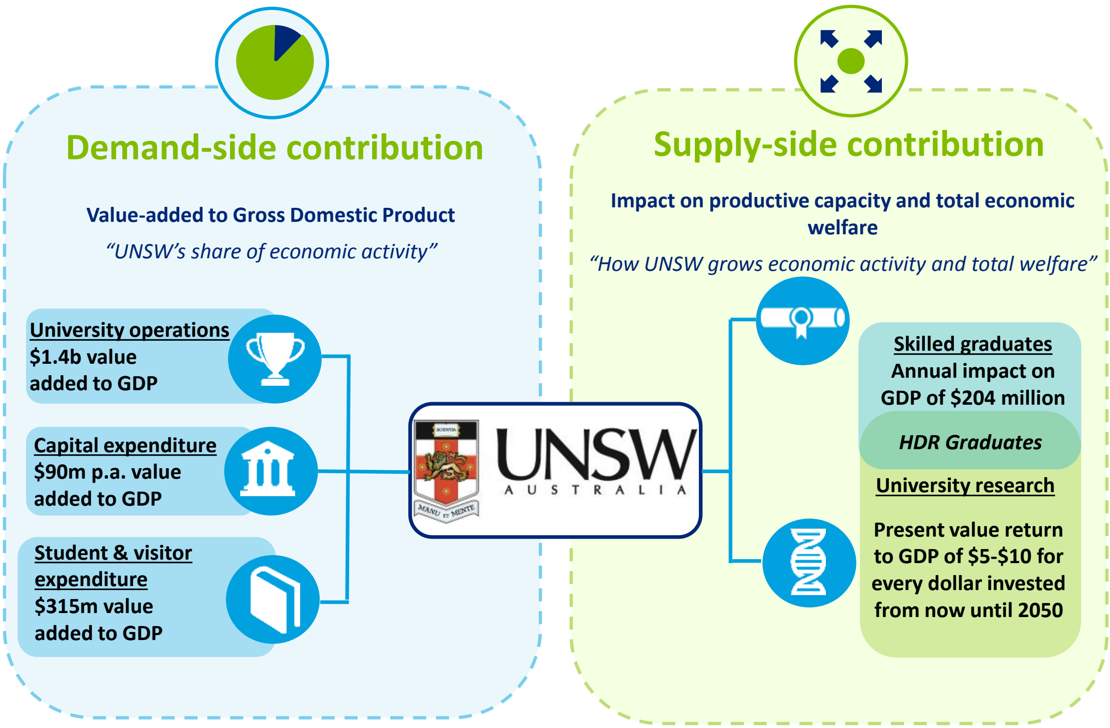
- Research into photovoltaic (PV) solar cells by UNSW in the 1990s led to **a significant increase in the efficiency of commercial PV cells**. During this period, UNSW's research program contributed significantly to improvements in the efficiency of solar panel production and helped to expand the global industry by directly training a large number of highly skilled graduates. The manufacturing capacity for cell technology based on UNSW's designs has been **growing close to $1 billion dollars per year since 2011**
- Memtec membrane research at UNSW in the 1970s and 1980s catalysed the development of membrane technology internationally, with a breakthrough in low-pressure microfiltration membranes. Directly, **it established UNSW as a world-leader in membrane research and established Australia as an industry leader through Memtec Limited**. Indirectly, the knowledge created has evolved into an industry which has transformed water treatment, and areas of environmental protection, manufacturing, and desalination. **Today, the global market for microfiltration (MF) membranes is estimated to be valued at billions of dollars**.
- A powerful software kit named Kakadu was developed by a UNSW researcher in the early 2000s. This allows developers to build compatible applications that utilise the internationally adopted standard for image compression, JPEG 2000. **Kakadu has become the market-leading software for JPEG 2000 image compression and has been licensed to more than 300 companies worldwide**, including several companies in the film production and distribution industry. Kakadu has been commercialised by UNSW

Innovations and **has generated tens of millions in economic benefits for its users and UNSW over the past 10 years**.

Combining the top-down, faculty-investment and case study approaches described above provides a comprehensive picture of the economic contributions of the research undertaken by universities such as UNSW. It is intended that these approaches could serve as a basis for assessing the economic contributions of other projects, faculties and universities, noting the limitations of each individual approach.

This comprehensive assessment of UNSW's economic contributions has demonstrated the sizeable economic benefits that Australian universities can make through the entirety of their activities. The quantitative estimates of these contributions for UNSW are summarised in Figure i below.

Figure i: The economic contribution of UNSW to Australia in 2014



UNSW, like many of Australia's universities, plays an essential role in supporting economic growth in Australia and NSW. Indeed, UNSW's teaching and research activities contribute to the achievement of both Commonwealth and State Government economic priorities. Most notably:

- As a world leading university, UNSW attracts a large number of international students who contribute to Australia and NSW's export earnings, representing a key source of income growth for the nation over the coming decades.
- UNSW is positioned to provide a strong and growing stock of human and intellectual capital, and ongoing discovery and knowledge exchange, to meet the changing demands of industry and underpin future economic growth. UNSW's role in this regard will only increase in importance as the structure of the NSW and Australian economies

continue to change and transition towards a knowledge-based economy, in response to overseas competition, digital disruption and technological transformation.

Australia's research universities will play a critical role in supporting future economic growth and wellbeing.

Based on the modelling undertaken for this study it is possible to estimate the economic consequences of varying levels of research expenditure in Australia.

Over the past 30 years real per capita expenditure on research in Australian universities is estimated to have grown by 4.7% per year on average. More recently, this rate of growth has moderated slightly, with average annual per capita growth from 2009 to 2013 estimated to be 4.3%. If real per capita spending on total university research increased by 4.3% in 2014, and was sustained out to 2050, it is estimated that GDP would increase by $47-$84 billion (in present value terms).

Compared to this trend scenario, if real per capita spending on total university research:

1. was halved in 2014 (to 2.1%), and this level of research expenditure was sustained out to 2050, GDP would be an estimated $23-$42 billion lower (in present value terms)
2. was raised to 5.7% in 2014 (the average growth of university research spending from 2004 to 2013), and this level of research expenditure was sustained out to 2050, GDP would be an estimated $16-$29 billion higher (in present value terms)

As with the estimates provided for UNSW's research expenditure, these results indicate a return to the economy of between $5 and $10 for each $1 invested in real per capita university research over a period of 35 years (in present value terms). This implies the equivalent annualised return from investments in real per capita university research lies in the order of 60%-100%. By way of comparison, the current annualised real return to paying down government debt is around 1.5% in real terms and the historical real before-tax rate of return on private investment is around 7%.[7]

In comparison to the results from the faculty investment approach these estimated rates of return are much higher. This likely reflects a number of complex factors, including the fact that top-down analysis of the impact of university research captures the more long-term and diffuse effects of university research which are not effectively captured in more micro-economic studies at a firm or industry level.

While these results demonstrate the potentially significant economic implications of changes to research expenditure, such decisions must of course be taken by policymakers in the context of the nation's wider economic and social priorities.

Universities will help Australia meet its productivity imperative to improve income growth over the coming decades.

To maintain national income levels and living standards over the coming decades Australia faces a considerable productivity challenge. As commodity prices fall and the returns from

[7] Further explanation of this result is included in paragraphs 2-3 on page 80 of this report.

the decade long mining boom recede Australia will need to find other areas of economic growth, principally in the form of higher levels of labour productivity.

Indeed, for growth in national income over the next decade to remain at the level experienced from 2001 to 2013, labour productivity will need to increase by almost 3% annually from 2014 to 2023 – around twice the level of productivity growth experienced between 2001 and 2013.

University higher education and research will play a key role in supporting this growth in labour productivity over the coming decades, through impacts on skilled workers and technological progress.

It is estimated that a 10% increase in university research spending (per capita) compared to 2013 levels would increase labour productivity by around 1.8% annually over the long run. Based on the estimates provided for this study, the productivity benefits of this investment in research would generate almost a third of the required rate of labour productivity growth required to maintain our growth in living standards over the next 35 years.

The findings of this study emphasise the important role that Australian universities can and will play in supporting economic growth and well-being in Australia over the coming decades. The study also demonstrates the significant economic returns that can be realised from society's investment in the teaching and research of universities.

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Key findings

University operations	• UNSW's ongoing operations contributed $1.76 billion to Australian GDP in 2014, including $1.58 billion to GSP in NSW • The total contribution of UNSW's operations to NSW is equivalent to 7% of the total education and training in the state or 12% of the state's mining industry output.
Skilled graduates	• University education added an estimated $140 billion to GDP in 2014, by raising the productivity of the workforce • Assessing the impact of just one cohort of UNSW undergraduate students, as an example, UNSW's 4,900 bachelor degree graduates from 2013 are estimated to contribute as much $204 million to Australia's GDP each year over their lifetimes, equivalent to around $41,500 per graduate per year. • UNSW's 8,100 bachelor and post-graduate degree graduates from 2013 will earn, in total, an estimated additional $56 million on average each year over their lifetimes.

University Research	• The stock of technology and knowledge attributable to Australia's universities is estimated to contribute approximately $160 billion to GDP in 2014, almost 10% of total GDP. UNSW's share of this contribution would be in the order of $15 billion.
	• UNSW's current annual expenditure on research of around $1.04 billion, if sustained over time, is estimated to:
	  ◦ increase GDP by between $106 and $190 billion over a period of 35 years, based on research expenditure of $17 billion (both in present value terms)[8]
	  ◦ indicating a return for the economy of between $5 and $10 for each $1 invested, over a period of 35 years (in present value terms)
	    ▪ this implies the equivalent annualised return from investments in real per capita university research lies in the order of 60%-100%
	    ▪ by way of comparison, the current annualised real return to paying down government debt is around 1.5% in real terms and the historical real before-tax rate of return on private investment is around 7%.[9]

Future investments in research	• Halving the growth in university research expenditure in 2014 from the current trend of 4.3% to 2.1% is estimated to cost the economy around $23-$42 billion in GDP (in present value terms, out to 2050). • Alternatively, increasing the growth in university research expenditure in 2014 from the current trend of 4.3% to the average of the past decade of 5.7% is estimated to raise GDP by $16-$29 billion (in present value terms, out to 2050).
Supporting Australia's productivity growth	• For growth in national income over the next decade to remain at the level experienced from 2001-2013, labour productivity will need to increase by almost 3% annually from 2014 to 2023. • A 10% increase in university research spending (per capita) compared to 2013 levels is estimated to generate almost a third of the required rate of labour productivity growth required to maintain our growth in living standards out to 2050.

[8] Further explanation of this present value calculation is included in footnote 28 on page 54 of this report.

[9] Further explanation of this result is included in paragraphs 2-3 on page 80 of this report.

1 Background

This chapter outlines the broader context and backdrop for the current project, the project's scope and the structure of the report.

1.1 Project context

While Australia's universities rely strongly on public funding, this funding is coming under increasing pressure, meaning universities increasingly need to demonstrate their value to students, government and the community.

Commonwealth expenditure on higher education in 2013-14 totalled $14.1 billion (Grattan Institute, 2014, pp. 42), and included:

1. Direct grants to higher education institutions, primarily for teaching of $6.2 billion;
2. Student loans which are taken out by students but paid to higher education institutions on students' behalf of $1.5 billion;
3. Student income support payments, which are paid directly to students of $2.9 billion; and
4. Direct grants to higher education institutions primarily for research of $3.0 billion (Australian Research Council, NHRMC, Research training and general research funding, other).

Fiscal pressures are increasing at all levels of government, reflecting the slowing down of Australia's mining boom, an ageing population that is reducing labour force participation, and several other factors. These pressures are resulting in government introducing and considering a range of measures to rebalance budgets and reduce government debt. Higher education expenditure is one area coming under the increasing scrutiny of governments.

Against this backdrop, it is essential that universities in Australia can demonstrate, and governments more fully understand, the value of universities to the economy. The nature and magnitude of universities' economic contributions are well understood in some areas, such as their ongoing financial operations and student expenditure. However, the economic contributions associated with universities' core functions – teaching and research – are not as well established.

Producing and disseminating new knowledge via research is a defining feature of universities in Australia, and a major part of their contributions to society. Research is a central component in the mission statements of Australian universities, a core part of their social responsibilities, as well as a government requirement to maintain the status of a 'university'.[10]

[10] To be a full Australian university, a higher education provider must be active in research across at least three broad fields of study (MCEETYA, 2007 in Grattan, 2014).

However, to date, the contributions associated with producing skilled university graduates, or research discovery and adoption, have rarely been assessed in their entirety, or indeed in a single, coherent framework.

Against this backdrop, UNSW commissioned Deloitte Access Economics to undertake a comprehensive assessment of the economic contributions of universities, with a particular focus on research, and taking UNSW to exemplify this contribution. This assessment:

- synthesises and builds upon the best available literature and approaches to estimate the economic contributions of the university's graduates and research
- informs UNSW's strategic directions, including its current strategy-setting process
- supports discussions with policymakers, and articulates how the economic contributions of universities align with current government priorities and future economic growth areas
- provides a robust and defensible framework for estimating the economic contributions of research for the sector, and other research universities

This report provides a rigorous framework rooted in the best-available literature for assessing the economic contributions associated with the entire gamut of university activities.

This report outlines how universities will contribute to Australia's future economic growth by supplying the high level of skills needed for our future workforce and driving our national productivity through research, as well as considering the economic consequences of reduced or increased investment in university research.

Finally, the report also considers linkages between UNSW's economic contributions and government economic priorities and growth areas, as well as opportunities for monitoring research impacts into the future.

1.2 Scope of the project

In light of the objectives for this project, the study has involved:

- An exhaustive review and synthesis of the best-available Australian and international literature on the economic contributions of universities, particularly the contributions of university research and development activity and expenditure
- Development of a rigorous, defensible and replicable framework for comprehensively assessing the economic contributions of research universities, for future use in estimating the contributions of other faculties and universities
- A comprehensive assessment and modelling of UNSW's economic contributions and impacts in the following areas:
    - UNSW's ongoing financial operations (payments to labour, capital and suppliers)
    - The expenditure of additional students attracted to NSW and Australia by UNSW, and the expenditure of visiting friends and relatives
    - UNSW's major capital expenditure
    - UNSW's highly skilled graduates, and their employment, earnings and contributions in the economy

    - UNSW's research and knowledge creation, and its direct, indirect and flow-on contributions in the economy
- An assessment of how universities will support future growth in Australia's economic wellbeing and address Australia's productivity imperative for the coming decades.
- An articulation of how UNSW's economic contributions link to current government priorities and economic growth areas.

The study has not included an assessment of numerous, important contributions universities make to Australia's social cohesion, including through the norms, values, attitudes, and ethics that it imparts to students - foundational for constructing healthy civil societies and cohesive cultures, and the very bedrock of good governance and democratic political systems.

1.3 Structure of the report

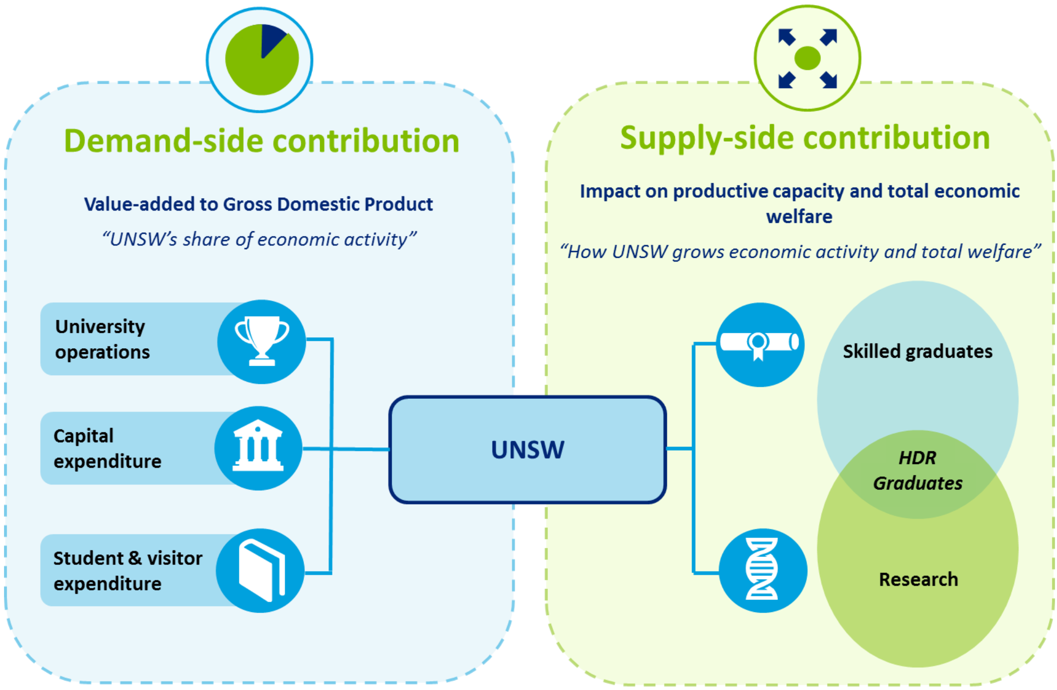
The report is structured as follows:

- **Chapter 2**: introduces a conceptual framework for the economic contributions of universities, including through research
- **Chapter 3**:
    - canvasses the existing literature on the economic contributions of universities, including the methodologies that have been employed to estimate these contributions, their strengths and limitations, and the resulting estimates.
    - Introduces the selected approaches for this study, which focus on estimating the economic contributions of the research undertaken by UNSW
- **Chapter 4**: presents the inputs to and outputs of the various modelling approaches utilised in this study, providing a comprehensive and authoritative assessment of the University's economic contributions through its ongoing operations, students and visitors, graduates and research
- **Chapter 5:** discusses how Australia's universities could support economic and productivity growth into the future, and play a key role in meeting the nation's future productivity imperative.
- **Chapter 6:** draws conclusions from the analysis on:
    - linkages between UNSW's economic contributions and government economic priorities and growth areas; and
    - opportunities for monitoring UNSW's research impacts in the future.

2 A conceptual framework of the economic contributions of universities

Like all universities, UNSW's contributions to the economies of NSW and Australia can be evaluated in terms of the goods and services *demanded* by the University, its students and visitors, and in terms of the outcomes the University *supplies* (i.e. skilled graduates and research output) which affect the productive capacity of the economy. A conceptual framework for these contributions is depicted in Figure 2.1 below.

Figure 2.1: Economic contributions of universities



2.2 Demand-side contribution

On the demand side, universities make economic contributions through their ongoing financial operations, the expenditure of their students and associated visitors, and major capital expenditure.

Universities contribute to the economy as economic entities:

- **Directly**: by employing staff and utilising ('renting') capital. A university's direct contributions are the sum of wages paid for labour (which include research, teaching and administration staff costs) and the university's gross operating surplus - calculated from the university's financial statements.

- **Indirectly**: by paying a range of suppliers in different industries and locations. Indirect contributions capture the flow-on economic activity of university operations, and typically arise from expenditure on items like marketing and equipment costs.

University direct and indirect contributions include economic contributions generated by existing capital such as buildings and infrastructure (this shows up in the gross operating surplus, which is interpreted as payments to capital). However, **new major capital expenditure** undertaken by universities will not yet show up in the operating statement, but can have significant **one-off economic impacts**, boosting construction activity and related industries.

While firms of any sort make economic contributions through their payments to staff, suppliers and profits, universities are relatively large economic entities that employ a relatively high proportion of highly-skilled staff.

Universities also contribute to the economy by attracting a range of **additional** interstate and international **students** to NSW, who **spend money** on a range of essential goods and services including accommodation, food and transport. Often the **families** and **friends** of these students **visit** NSW, bring **additional export earnings** into the state.

While the demand-side contributions of universities are well understood and often measured in economic terms, the supply-side economic contributions of universities are not as well established or rigorously assessed in the existing literature.

2.3 Supply-side contribution

On the supply side, universities make economic contributions through producing graduates who can perform highly-skilled jobs, and through undertaking research and knowledge creation, all of which adds to the productive capacity of the economy and long-term growth.

2.3.1 Highly skilled graduates

University teaching and learning provides graduates with increased 'human capital' - skills and abilities that they go on to supply in the labour force. The human capital associated with undertaking higher education can be said to **increase graduates' productivity in the workplace** (over and above their productivity had they not undertaken higher education). This leads to a supply of highly-skilled individuals who can 'produce more with less', with this increased human capital and productivity reflected in:

- **higher wage premiums** at the individual level
- **higher output and income** at the economy level

In addition to supplying highly-skilled graduates, undertaking research is another way universities can contribute to the productive capacity of the economy.

2.3.2 Research

The economic contributions of research are a function of several factors, including the type of research that is undertaken, and the way and speed with which the knowledge generated by the research flows through to other agents. These contributions can differ in how directly or indirectly they relate to the research activity undertaken, and can be measured in a variety of ways, notwithstanding a number of inherent challenges associated with accurately quantifying these contributions. Understanding the complex nature of research, its transmission mechanisms and measurement issues is essential to the development of a comprehensive and defensible assessment of the economic contributions of UNSW's research.

This section provides a conceptual basis for a detailed review of the literature on approaches to measuring the economic contributions of university research in chapter 3, and the application of a set of approaches in chapter 4. The section:

- considers the **types** of **research** that exist, and relative applicability to industry;
- maps out the **channels** by which **research** activity can **flow** through to different end **users**, **uses**, and **impacts**;
- provides a conceptual, organising **framework** for the **economic contributions** of university research, including **direct**, **indirect** and **flow-on** contributions;
- describes the main ways the economic contributions of university research can be **measured**, namely in terms of economic value-added (GDP), consumer surplus and productive capacity; and
- and explains the **challenges** with **measuring** the economic contributions of research

2.3.2.1 Types of research

The economic contributions of UNSW's research activity are as broad and varied as the research itself. Illustrating this variety, the Australian and New Zealand Standard Research Classification (ANZSCR) provides three different ways to classify research activity[11]:

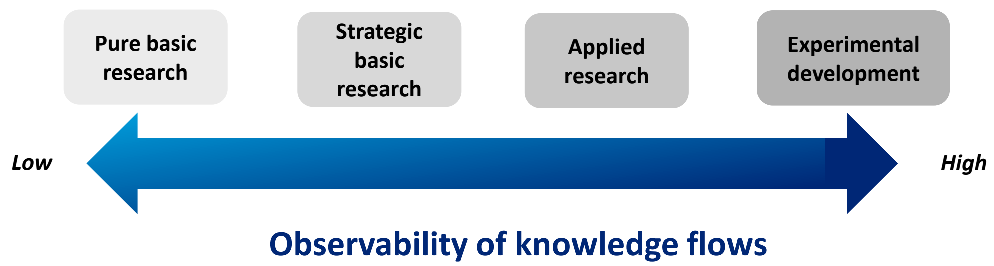
1. Fields of Research (FOR): categorises research activity according to the educational/industry 'field' to which the research relates. There are three levels of categorisation – Divisions, Groups and Fields. For example, a piece of research on developing membrane filtration technology can be classified under 'Engineering' (Division), 'Chemical Engineering' (Group), and 'Membrane and Separation Technologies' (Field).
2. Socio-economic Objectives (SEO): categorises research activity according to the intended socioeconomic objectives of the research, such as improving consumer products, health, education, or the environment. There are four levels of categorisation – Sector, Divisions, Groups, and Objectives. For example, a piece of research that seeks to improve solar cell efficiency can be classified under 'Economic Development' (Sector), 'Energy' (Division), 'Renewable Energy' (Group), and 'Solar-Photovoltaic Energy' (Objective).

[11] http://www.abs.gov.au/ausstats/abs@.nsf/Latestproducts/1297.0Main%20Features32008?opendocument&tabname=Summary&prodno=1297.0&issue=2008&num=&view=

3. Type of Activity (TOA): categorises four types of research activity based on their direct applicability to industry.
    - **Pure basic research** - work undertaken for the purposes of acquiring new knowledge and adding to the existing stock of knowledge out there.
        - Example: Developing theorems in high-level abstractions of pure mathematics, such as ring theory and group theory.
    - **Strategic basic research** - work undertaken primarily to acquire new knowledge with a specific application in view
        - Example: Developing a methodology for finding prime numbers – with the anticipation it will one day be useful in fields such as cryptography.
    - **Applied research** - work undertaken to acquire new knowledge directed into broad areas related to practical discoveries
        - Example: Developing a recovery model for mental illnesses which could potentially be adopted by psychologists to help treat patients.
    - **Experimental development** - work which uses existing knowledge to produce new materials, products, devices, policies, systems, and processes (or improve existing ones)
        - Example: Developing advanced optical lenses for use by the film industry under extreme lighting conditions.

From the TOA categorisation, it is apparent that if an evaluation were to move away from examining experimental development to activity types such as strategic and pure basic research, the ability to identify immediate linkages between research activity and economic impacts becomes weaker (as depicted in figure 2.2). As such, any effective and impactful economic evaluation of research will likely need to take place towards the applied and experimental development end of the spectrum.

Figure 2.2: Research types and knowledge flows

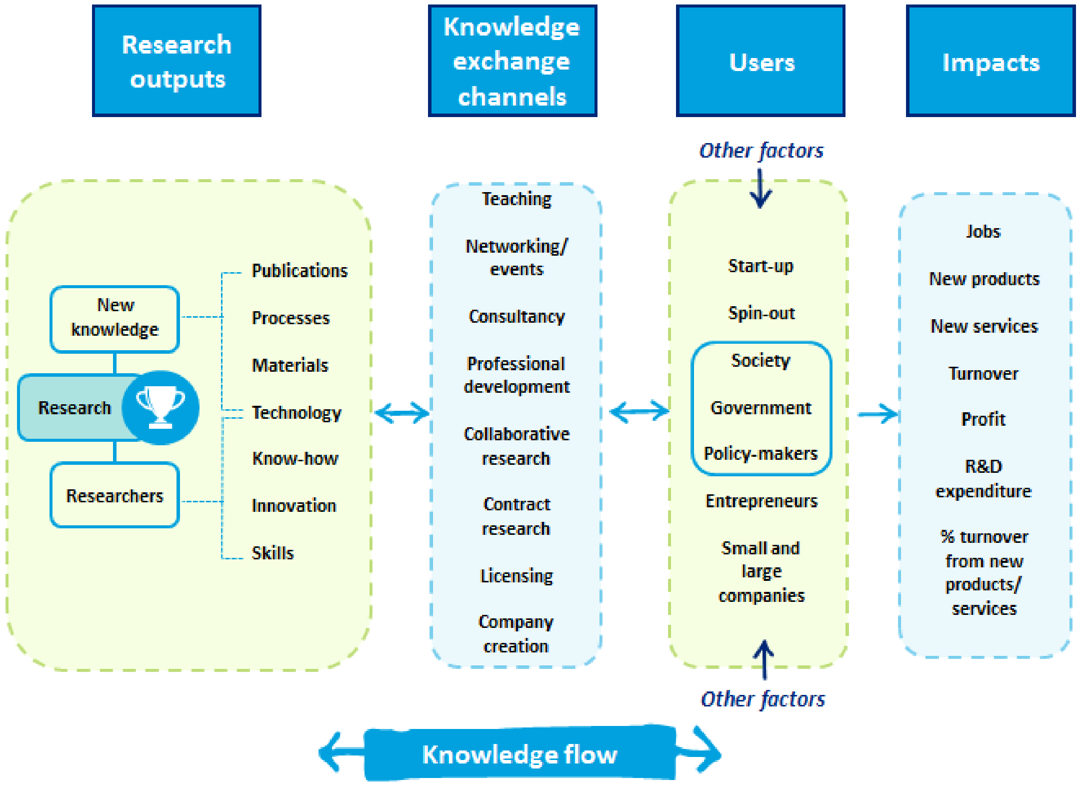


2.3.2.2 Research and knowledge exchange

There are several channels through which university research can influence economic activity, including consultancy, collaboration, contract research, publication, licensing and teaching.

It is often strategic, impact-driven, goal-orientated research that drives direct application and progresses entire industries in the broader economy. This is captured in the diagram below via the notion of a **"knowledge exchange"** system were the university actively disseminates knowledge with economic, social, and cultural benefits to groups such as industry, NGOs, and public bodies.

Figure 2.3: Research and knowledge exchange: A stylised model



Source: Dr Kevin Cullen, CEO, UNSW Innovations

The knowledge exchange framework posits that basic research generated by the university can be exchanged to other bodies through activities such as collaborative research, contract research, and consultancy by the university (Cullen, 2015; Cullen, 2006). This allows knowledge with a specified industry end-use to be effectively transferred from the university to users in government, industry, and broader society, which then in turn has economic effects such as creating new products, services, or jobs.

2.3.2.3 Channels of economic contribution

Research can be causally linked to a number of impacts. As defined by the CSIRO (Deloitte Access Economics, 2014), a research impact can be defined as:

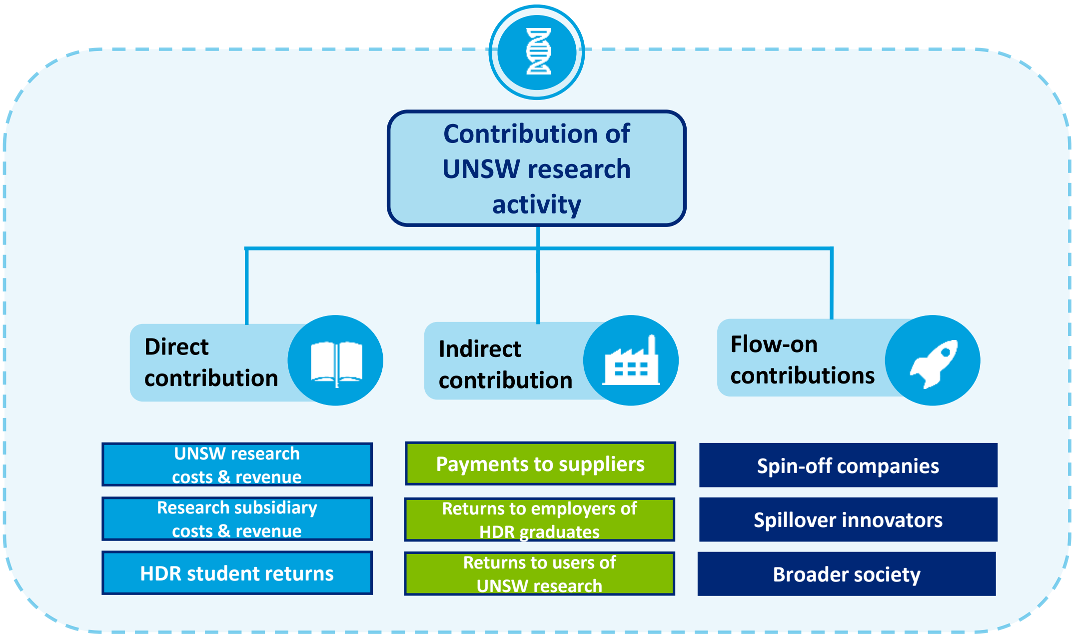
> *An effect on, change or benefit to the economy, society or environment, beyond those contributions to academic knowledge. Impact includes, but is not limited to an effect on, change or benefit to the activity, attitude, awareness, behaviour, capacity, opportunity, performance, policy, practice, process or understanding of an audience, beneficiary, community, constituency, organisation or individuals in any geographic location whether locally,*

regionally, nationally or internationally. Impact also includes the reduction, avoidance or prevention of harm, risk, cost or other negative effects.

A subset of these impacts will be explicitly economic in nature, and from this it is possible to make an evaluation of a research project's economic contribution. These contributions can be complex and difficult to discern, and will vary widely from project to project. For example, research can increases the stock of knowledge and expands the technological opportunities available to society; new graduates with research experience can enter into industry, bringing knowledge of recent research and useful skills such as problem-solving and research; and research conducted in research institutions can generate spin-off companies which contribute to the economy.

The *economic contributions* of research can be categorised into three interrelated categories. Direct contribution captures impacts on those from UNSW directly involved in the research; the indirect contribution captures impacts on suppliers to and consumers of UNSW research output; and the flow-on contributions capture spill-overs, spin-offs, and externalities.

Figure 2.4: Economic contributions of university research



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The direct, indirect, and flow-on economic contributions accrue to different parties in the economy, such as firms, research institutions, and households.

Table 2.2: Parties affected by research impacts

Channels of economic contribution	Parties affected
Direct	• The research institution (UNSW) and its subsidiaries (e.g. UNSW Innovations) • HDR graduates
Indirect	• Intermediate suppliers of research activity, employers of HDR graduates • Industries that adopt UNSW research technologies • Related economic impacts (such as the effect on consumers of an industry's products)
Flow-on	• Industries that may or may not have adopted UNSW research technologies • Spin-off firms • Other groups in the economy

Direct (operational expenditure and revenue, graduate returns)

The direct economic contributions of UNSW research flow to the parties at UNSW engaged with the research activity. They include the costs and gains to UNSW which can be attributed to the research activity being conducted and/or completed, and the returns to HDR graduates which were part of the research activity.

- First, the direct contribution captures the operational expenditure of the research project or program – that is, the capital and labour costs which were involved in undertaking and completing the project in question.
- Second, it takes into account the revenue earned by UNSW (or its subsidiaries) as a result of the core research program revenue from commercialisation, patents, licensing, and additional research funds
    - Ideally, the revenue would be directly linked to a research project or activity previously or currently undertaken within the UNSW Faculty of Engineering. Other relevant subsidiaries may be included, where applicable to the Faculty of Engineering
- Last, the direct contribution captures the returns to HDR graduates that were involved in the research project. This is the increase in earnings which Higher Degree Research graduates experienced as a result of being involved in a particular field of research or a particular project.

Indirect (suppliers, employer returns, consumer surplus)

The indirect economic contributions of UNSW research flow to parties other than UNSW and its researchers. They include gains to the intermediate suppliers of the research activity, the returns to the employers of HDR graduates, and the returns to the consumers of UNSW research (such as industries which adopt technological innovations created by the UNSW Faculty of Engineering).

- The first indirect contribution to consider is the return to intermediate suppliers of inputs into the research activity. These intermediate inputs can include raw materials, energy, and semi-finished products that were used to help UNSW conduct and complete a particular research project.
- The second contribution is the return that employers of HDR graduates from graduates that were engaged with UNSW research projects.
- The last, and usually the most important, channel of contribution is the consumer surplus to firms or households in the economy which consumed the research outputs.
    - The specifics of how these benefits (or costs) are generated and distribute is highly complex and often unique to each research project.

Flow-on (spin-offs and spill-overs)

The flow-on economic contributions of UNSW accrue to the remainder of the economy by way of the unintended effects of the research, such as technological and industry spillovers, economic externalities, the creation of new spin-offs firms which emerge as a result of research activity.

- One major flow-on affect is technological spin-offs as a result of the research. These are instances in which the research results in an entirely new product being produced.
    - For example, NASA has produced a number of technologies which have led to the invention of entirely new spin-off products. The 'space blanket', a low-weight sheet of plastic coated with metallic reflecting agents, was first as a sunshield for space vehicles. It has since been adapted for commercial use in first aid kits, as outdoor equipment, and for emergency and survival use.
- Similarly, spin-off firms can also develop, commercialising technological inventions that arose as a result of university research that would have otherwise remained unexploited. For example, a 2009 study found that companies found by MIT graduates (many of them being spinoff companies) generated hundreds of billions of dollars in the United States (Roberts and Eesley, 2009).
- Further, the use of this research within the economy can generate positive and negative externalities that may accrue to a variety of groups in the economy. These include externalities.
    - Due to the intrinsic unpredictability and measurement difficulties associated with spin-offs and externalities, it is often the case that their effects will be estimated using approximations from the literature, or left as a qualitative description.

2.3.2.4 Measures of economic contribution

There are a number of ways in which the economic contribution of research can be viewed. Four common ways is to examine the way research activity affects economic value-added; total economic welfare; productive capacity; and non-economic measures.

Economic value added (Gross Domestic/State Product)

Value added measures the value of output (i.e. goods and services) generated by the entity's factors of production (i.e. labour and capital) as measured in the income to those factors of production. The sum of value added across all entities in the economy equals gross domestic product. Given the relationship to Gross State Product (GSP) or Gross Domestic Product (GDP), the value added measure can be thought of as the increased contribution to welfare

Productive capacity (technology and productivity)

The economic contributions of research can also be measured in terms of their effect on the productive capacity of the economy – the value of output that can be produced with a given value of inputs. A common measure of this in the literature is total-factor productivity (or multi-factor productivity) which is often measured as a residual of effects in total output not accounted for by factor inputs. Another common measure is labour productivity, which simply measures the total amount of output per hour worked in the economy.

The idea is that research can have an impact by expanding the stock of technology augmented labour and capital available to the economy. This technological augmentation results in the economy "doing more with less" - the economy is able to expand total income from the same basis of resources. This is different to economic value-add which is merely an accounting exercise that carves up existing total output and attributes contribution to entities and industries based on the 'value' they add to intermediate inputs through the application of capital and labour.

The actual mechanisms for how research accomplishes this can vary. Research increases the stock of knowledge and expands the technological opportunities available to society. Firms can draw on this stock by purchasing IP or commercialisation licenses and utilise the technology to improve the efficiency of their production, and increasing their chances of finding and implementing productivity-improving changes. Further, new graduates with research experience can enter into industry, bringing knowledge of recent research and useful skills such as problem-solving and research. Their enhanced competency and skills can be viewed as a labour productivity improvement.

Total economic welfare (consumer surplus)

Total economic welfare is an important measure that is not picked up in national accounting exercises. It is essentially the total pecuniary benefits from some observable change in the organisation and utilisation of scare resources in the economy. It includes both the market value of the transactions that represent this organisation as well as the monetary value individuals place on the outputs of the economy, above and beyond the price that they pay.

Consumer surplus essentially recognises that in a competitive market economy, technological advancements that lower production costs and improve the quality of goods and services may not be realised in the form of income paid to labour and capital if prices are set in a perfectly competitive market. Then most of the pecuniary economic return is instead accrued to consumers. If perfect price discrimination existed, and vendors could charge goods and services as to capture the entire surplus that could potentially accrue to consumers, than Gross Domestic Product would equal total economic welfare, but this is very rarely the case in the actual economy.

Non-economic measures

While not a primary focus of this economic study, a range of non-economic measures can be used to quantify the impacts, dissemination or reach of research. A real world example of this is the UK's Research Excellence Framework (REF) which tries to assess the 'originality, significance and rigour' of research; the 'reach and significance' of its impacts on the economy, society and/or culture; and how it contributes to the 'vitality and sustainability' of the research environment it inhabits. The REF is used to inform research funding decisions of British higher education institutions.

In addition, research can have a range of less quantifiable non-economic benefits, such as These include the benefit the general public receives from being informed and educated about the latest research breakthroughs, which can elicit a sense of enjoyment or fascination in 'knowledge for knowledge's sake'. The results of research could also lead individuals in the economy to change their preferences and decision-making around issues of culture or politics which are difficult to quantify economically. In short, research may have important nonpecuniary returns that need to be carefully considered alongside its economic returns.

2.3.2.5 High-level challenges with measuring research contributions

The existing literature is uniform in its acknowledgement of the range of inherent complexities associated with accurately and defensibly estimating the economic contributions of university research (Group of Eight, 2011; Productivity Commission, 2007; Salter and Martin, 2001). These challenges can be summarised in the following list:

- **External context**: Whether or not research is successfully transferred and applied into the broader economy is often dependent on numerous and complex economic, social, and political factors in society at large. For example, after World War II, advances in the research and application of technologies such as aerospace engineering and nuclear physics expanded significantly in the United States within the unique contextual factors of the Cold War.
- **Time lags**: Significant time lags also exist between the creation of knowledge and the diffusion of it into the broader economy.
- **Dynamic value**: The value of knowledge can fluctuate over time and not all knowledge is immediately useable by the economy. Similarly, research which was anticipated to be economically useful may become obsolete due to advances in competing research.
- **Uncertain value**: It is difficult to predict the usefulness of a certain piece of knowledge to the economy. For example, when the first working laser was invented, it was described as a "solution looking for a problem".

- **Attribution**: Research projects are often a collaborative effort between a university and other institutions, industries, and government bodies, with varying shares of contribution.
- **Negative impacts**: Research could create negative economic impacts initially if adopted and may only have a positive economic impact further into the future. An example of this could be environmental research which leads to sustainable practices which harm particular industries in the short-term, but actually mitigate much larger negative economic impacts in the long-run.
- **Dependency**: Whether progress in one area of research will result in an economic impact may be dependent on the progress in a related area of research. For example, a piece of medical research may not be able to progress without parallel advances in molecular chemistry.
- **Isolation**: In a complex world, almost all research builds on earlier research that preceded it, making isolation of the impacts challenging in any case. That is to say, research advances from "standing on the shoulders of giants".

These challenges in measurement are exacerbated in the cases of less applied types of research, such as pure research.

In light of the complex nature of research, its transmission mechanisms and measurement issues, several distinct and often highly technical approaches have been employed in the existing Australian and international literature to estimate the economic contributions of research. These have informed Deloitte Access Economics' approach to undertaking a comprehensive and defensible assessment of the economic contributions of UNSW's research.

3 Approaches for estimating the economic contributions of universities

While approaches to estimating the economic contributions of universities are well established on the 'demand side', Deloitte Access Economics has conducted a thorough review of Australian and international literature to:

- identify the most suitable approaches to estimating UNSW's economic contributions on the 'supply side', and
- synthesise the most relevant and reliable existing estimates of university economic contributions

In light of the complex nature of research, its transmission mechanisms and measurement issues, several distinct and often highly technical approaches have been employed in the existing Australian and international literature to estimate the economic contributions of research. These have ultimately informed Deloitte Access Economics' approach to undertaking a comprehensive and defensible assessment of the economic contributions of UNSW's research, as an illustration of the impact that university research can have on the Australian economy.

3.1 Demand-side modelling

The approach to estimating the economic contributions associated with UNSW's ongoing financial operations, the expenditure of their students and associated visitors, and major capital expenditure is well established and frequently used in economic studies.

Economic contribution studies quantify measures such as value added, gross output and employment associated with a given industry or firm, in a historical reference year. The economic contribution is a measure of the value of production by a firm or industry. UNSW's economic contributions are quantified using Deloitte Access Economics' in-house integrated regional input-output model (known as DAE-IRIOM). The model enables us to estimate the economic contributions of UNSW's ongoing activity and students in a rigorous, tested economic framework.

The data used to estimate the economic contribution of UNSW on the demand side falls into the following broad categories:

- UNSW's enrolment statistics by student characteristics
- UNSW's financial information (including information on intermediate inputs and suppliers)
- UNSW's student expenditure by domestic and international students, and associated expenditure of visiting friends and relatives

The majority of this data comes from UNSW itself. Data on student expenditure comes from the Universities Australia publication University Student Finances in 2013.

The model outputs the total economic contribution of UNSW, including all direct expenditure by the University, its students and associated visitors, as well as the flow on to other sectors and regions of the economy. The primary measure is 'value added', which measures the value added to intermediate inputs by the application of capital and labour. 'Value added' is the sum of:

- **Payments to labour**: This represents the value of output generated by UNSW's direct labour inputs, as measured by the income to labour.
- **Payments to capital, measured by gross operating surplus (GOS)**: GOS represents the value of income generated by UNSW's direct capital inputs, generally measured as the earnings before interest, tax, depreciation and amortisation (EBITDA).
- **Tax on production less subsidy provided for production**. This generally includes company taxes and taxes on employment.

The sum of value added across all entities in the economy equals gross domestic product (GDP). UNSW's economic contribution is also reported in equivalent employment numbers (FTE).

The economic contributions associated with the expenditure of UNSW students and visiting friends and relatives are also estimated using the DAE-IRIOM, and capture how this expenditure flows through different sectors and regions of the economy.

While the contribution to the economy of UNSW's existing capital stock is captured in this approach, recent capital investments may not have yet fully translated into new capital stock or generated a sizeable return as measured by GOS, despite having a material impact on the economy. As such Deloitte Access Economics also utilised the DAE-IRIOM to estimate the flow-on contributions associated with UNSW's recent major capital expenditure.

3.2 Supply-side modelling

3.2.1 Skilled graduates

3.2.1.1 Literature review

Economists have long been interested in the labour market benefits of higher education, and there has correspondingly been a great deal of research attempting to quantify these benefits (see, for example, Ashenfelter et al, 1999; and Card, 1999).

Irrefutable evidence on the benefits of education has proved somewhat elusive; reflecting the fundamental problem that social scientists and economists cannot observe what an educated person would have experienced had they not obtained their education. Though, current evidence points to the conclusion that significant benefit is more highly likely to be present than not, particularly for education in early years (Chetty et al, 2011).

Human capital theory is perhaps the most widely accepted model used to analyse the contribution that higher education makes to individuals earnings and productivity, and subsequently to economic and social prosperity (McMahon, 2009; Leigh, 2008). Human capital is essentially the skills and abilities that individuals embody which they can productively apply to the workplace or to their personal lives more generally. These skills and abilities are in part explained by an individual's *innate* ability, but they are also acquired through experience and formal education (Borjas, 2010). The human capital theory of education posits that skilled graduates embody greater human capital as a result of their university education, which increases their productivity in the workplace (reflected in the form of higher wages) and quality of life more broadly.

As such, it plays a key role in supporting productivity growth for all nations, the primary driver of improved living standards over time (Mankiw et al, 1992). Indeed, as noted by Krugman (1994):

> *Productivity isn't everything, but in the long run it is almost everything. A country's ability to improve its standard of living over time depends almost entirely on its ability to raise its output per worker.*

Growth accounting analysis in the UK has indicated that the ongoing accumulation of skilled university graduates contributed to around 20% of all GDP growth in the UK from 1982-2005. This same analysis found that a 1% increase in the share of the workforce with a university degree raises long run productivity by 0.2-0.5%. This means that at least one-third of the 34% increase in the labour productivity growth that occurred between 1994 and 2005 can be attributed to the accumulation of skilled university graduates in the labour force (BIS, 2013).

This overall finding, of the significant contribution of university higher education to productivity growth, is consistent for most OECD countries including for Australia. Indeed, there is newly emerging theoretical evidence that these more traditional approaches to estimating the contribution of human capital accumulation to income growth and living standards at best present *a lower bound* of the total contribution of formal (university) education (Jones, 2014).

For graduates themselves, there is considerable evidence demonstrating that higher education contributes to higher lifetime earnings, reflecting – in part – improved productivity and employment opportunities (Card, 1999). While there is a wealth of international empirical research on this topic is not reproduced here.

In Australia, there is a small, but growing, body of evidence that shows that individuals with university higher education receive higher wages, are more likely to be employed and commit more hours to the labour force than individuals without a higher education degree (Wilkins, 2015). For example, some estimates show that an individual completing a bachelor degree in Australia could expect an average private rate of return of 15.3 per cent for males and 17.3 per cent for females, compared to someone who had finished Year 12 (Leigh, 2008).

As a further example, Corliss et al (2013) find that the rate of return in 2006 for all higher education graduates was 12 per cent for females and 15 per cent for males. The authors found also that, while there are considerable differences in rates of return according to gender and discipline of study, there also appear to be important business cycle effects on the rate of return to a university degree. Nonetheless, their results show that, for the average person, there are strong incentives to complete university degrees, and that the private rate of return compares favourably with the real long term real bond rate.

Finally, a recent study of Household, Income and Labour Dynamics in Australia (HILDA) Survey by Wilkins (2015) found that individuals receive significant returns from higher education in Australia in the form of an increased likelihood of being full-time employed and higher weekly income. Importantly, in his study Wilkins explicitly controls for demographic factors and cognitive ability which allow him to conclude that the "estimates should at best be regarded as tentative evidence of the causal effects of education" (Wilkins, 2015, pp. 70-71). These estimates may present the most contemporary and robust estimates of the returns to higher education for individual skilled graduates in Australia.

3.2.1.2 Selected approaches

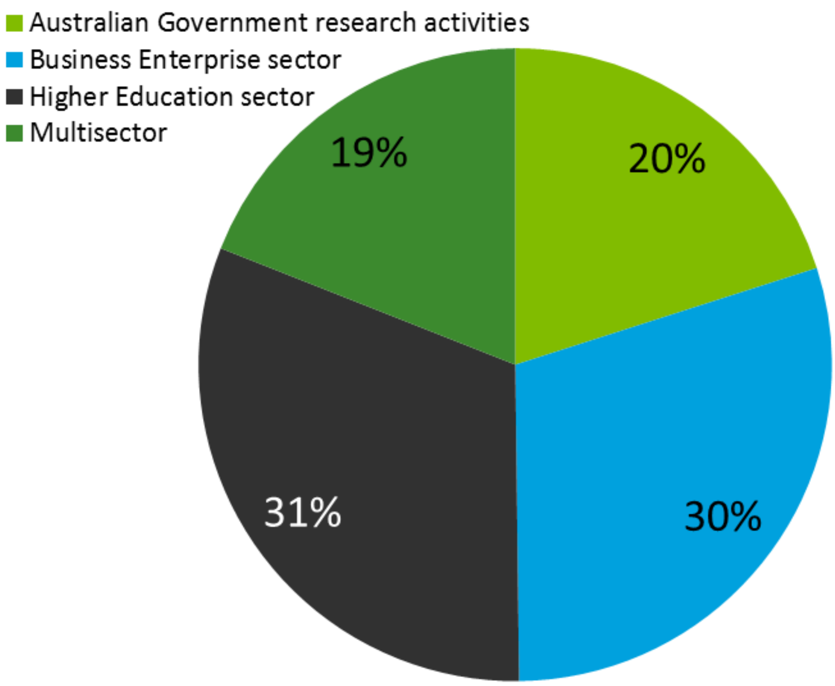
Following the general approaches to estimating the contribution of university teaching and learning identified in the literature, our approach to measuring the economic contributions of skilled graduates comprises two parts:

1. Through a cross-country model of economic growth, the contribution of UNSW's skilled graduates to productivity and GDP growth is estimated. This modelling extends the neo-classifical Solow growth model adopted by Mankiw et al (1992) by incorporating tertiary human capital as an additional input in the aggregate production function of the economy. The model estimates the share of total economic output attirbiutable to all individuals with a tertiary degree in Australia and then estimates the share of the contribtuion attributable to one year (2013) of bachelor degree graduates from UNSW.
2. Using findings from the Australian literature on returns to higher education and data from UNSW, the ABS Census and the Department of Education, the total return to private individual lifetime earnings for all 2013 bachelor and post-graduate degree students is estimated, relative to what they would have earned with a lower level of educational qualification.

3.2.2 Research contributions

In addition to teaching, one of the major activities of universities is to undertake research. According to the department of Industry and Science, in 2014-15, around $9.1 billion was budgeted by the government for R&D and innovation. Around 31% of this amount was allocated to the higher education sector making it the largest recipient of this funding.

Figure 3.1: Proportion of Research and Innovation budgeted funding to various agencies (2014-15)



Source: Department of Science and Industry (2015)

In the higher education sector, around 68 percent of the funding comes in the form of performance-based block funding and provided through a number of 'performance-based' arrangements, such as the Research Training Scheme (RTS), the Institutional Grants Scheme (IGS), the Research Infrastructure Block Grants scheme (RIBG), and the Australian Postgraduate Awards scheme (APA). Australian Research Council (ARC) funding accounts for 30.5 percent of all funding to higher education. Other R&D support accounts for 1.5 percent.

The statistics above suggests that research is a major activity for Australian universities. It is the public nature of knowledge and the positive externalities associated with the knowledge which suggests the need for government intervention; since otherwise a suboptimal amount of research would be undertaken if left to its own devices. The role of government funding in supporting R&D and innovation has been a topic of persistent interest in both academic and policy circles. Much of this interest derives from the perceived, yet often unreliably quantified, relationship between R&D, innovation and productivity growth, which in turn is a significant contributor to long-term economic growth and well-being.

This section provides a detailed review of the literature which attempts to measure the economic impacts, contributions, and benefits of research, with a particular focus on university research. This section:

- gives a broad overview of the economic thinking that exists on the ways in which research activity channels into the real economy;

- identifies **three levels of analysis** at which the literature looks at the relationship between research and the economy (economy-wide, the program/university/faculty level, and the individual research project/case study level); and
- articulates the commonly used methodologies with each of these levels of analysis as well as describe key examples of studies which have used these methodologies.

3.2.2.2 Literature review

The accumulation of knowledge through research and its application to productive activity is at the heart of modern economic theories explaining economic growth. This idea is the core of endogenous growth theory, advanced by Paul Romer (1990), Robert Lucas Jr (1988) and Aghion and Howitt (1992). At the core of this theory, sustained economic growth is driven by positive externalities and spillover effects of a knowledge based economy. To elaborate, sustained investment in human capital, innovation and knowledge leads to positive spillovers which drive productivity, thus leading to economic growth. In addition to the value of innovation to raising productivity, endogenous growth theory also recognised the possibility that productivity benefits from research and successful innovations are not fully absorbed by the innovating entities but, rather, they diffuse through the rest of the economy. This diffusion, leads to positive externalities in growth and the productivity performance of the other entities using this innovation.

A unique feature of this is the possibility that knowledge can lead to increasing returns to scale. Knowledge, unlike many other economic inputs is non-rivalrous and can often be non-excludable i.e. a public good. As such, R&D spillovers can be cheaply done and generate significant benefits to those other than primary investors. As Arrow (1962) had noted, discoveries can be copied, knowledge embodied in capital can be accessed through reverse engineering, and researchers can leave organisations, taking technical insights and expertise with them. This means that knowledge can result in increasing returns to scale in (New Zealand Treasury, 2008).

It is through these channels that the knowledge generated by universities flows through to, and creates spillover effects throughout, the economy, and so drives productivity growth To highlight this point, research discovery and adoption conducted by Australian universities can improve the productivity of industries by creating new systems, materials, and products which may be adopted by various industries. More specifically, Salter and Martin (2001) note that research projects can contribute to the economy in a number of ways, including:

- Increasing the stock of useful knowledge that firms can draw upon to increase their chances of finding and implementing productivity-improving changes
- Generating generate spin-off companies which contribute to the economy
- Stimulating new relationships between individuals and organisations in industry, government, and research institutions that can lead to the further development of economically beneficial learnings and innovations
- Training skilled graduates can enter into industry, bringing knowledge of recent research and useful skills such as problem-solving and research.
- Creating new scientific instrumentation and methodologies that can be used by industry.

It is important to note that university research discovery and adoption will have an economic impact insofar as there are mechanisms for effective knowledge transfer. This is because research activity relates not only to the discovery and creation of new knowledge but also the costs and effort associated with research dissemination and adoption. Innovation, in and of itself, will not necessarily translate into economic activity. Rather, it is the application of that technology and its introduction into the marketplace that results in economic growth.

There are numerous ways of appraising these effects in the literature, by looking at it from an economy-wide perspective; from the level of a program, university, or faculty; and from a research project or case study approach. Each perspective has at least one methodology which is commonly used to examine it.

Table 3.1: Common methods used for various research perspectives

Perspective	Methodology
Economy-wide or top-down studies	Macro-econometric studies
Program, university and faculty-level studies	Computable general equilibrium
Research project or case study approaches	Micro-econometric studies; case studies

Macro-econometric studies are widely used by academics due to its stronger theoretical links (to growth theory) and relatively greater data availability. Generally speaking, it is used by high profile academics such as Robert Barro to quantify these relationship which helps give the methodology credibility. It continues to be a widely used method in the academic literature and refinements of these technique continues and is of great interest as reflected by new publications e.g. Jones (2014) in leading economic academic journals such as American Economic Review.

One of the weaknesses of these studies is that it doesn't provide significant granularity to estimate the impact of a particular piece of research; that is, it doesn't account for the idiosyncratic nature of a piece of research. Furthermore, it is at best an indirect measure of the impacts of research; that is, it aggregates total research and estimates the relationship of expenditure and productivity and does not measure the direct impact of the research on the economy.

More direct methods which evaluate the impacts of research at a program, university and faculty level have also commonly been employed in the literature. These studies and methods directly measure the impact of a piece of research on the economy through the use of micro-econometric analysis. As such, it fills the gaps left by the more indirect macro-econometric approach and provides a more accurate range of estimates for impact of the productivity impact of the university.

A summary of the different approaches and resulting estimates from economic contribution studies of university research is presented below.

Table 3.2: Summary of main results in the literature

Study	Estimated results
Economy-wide or top-down studies	
Australia	
Burgio-Ficca (2004)	• 0.117% increase in GSP for a 1% increase in Higher education R&D stock. • Statistically significant at 10% level
Elnasri and Fox (2014)	• A 1% increase in higher education spending will increase MFP by 0.305% • Statistically significant at 5% level • If the higher education stock is lagged for one period, 1% increase in higher education spending will increase MFP by 0.352% • Statistically significant at 1% level
Productivity Commission (2007)	• They found estimates of the responsiveness of GDP or multifactor productivity to a 1% change in R&D, typically fall between 0.05 % and 0.45% • Their own estimates found that between 1983 and 2003, the contribution of publicly supported R&D was around $54 billion (in real terms), and $6.5 billion in 2004-2005.
UK	
Frontier Economics (2014)	• A 1% increase in higher education spending as a proportion of market sector value added will increase MFP by 0.4844% • Statistically significant at 5% level
OECD	
Guellec et al (2001)	• The long-term elasticity of government and university-performed research on productivity is around 0.17, i.e. a 1% increase in government and university-performed research spending will increase MFP by 0.17%. • Statistically significant at 5% level
Program, university and faculty-level studies	
Allen Consulting Group (2011)	• Allen Consulting Group examined the combined economic impact of four research institutions within The University of Queensland and computed that in real terms the institutes are expected to increase GDP over the period 1999-2012 by between $3.4 billion and $3.7 billion (in 2005-06 dollars). • Queensland GSP was calculated to increase by between $8.2 and $9.0 billion over this same period.
Allen Consulting Group (2005)	• The impact of the CRC programme between 1992 and 2010. Resulted in GDP that was cumulatively higher by $1.14 billion than would have occurred had the money spent on the CRC Programme instead gone to general government expenditure.

Centre for International Economics (2015)	• Total impact of advanced physical and mathematical sciences amounted to over 22% of Australian economic activity, or about $292 billion per year. • 7% of total Australian employment (or 760,000 jobs) is directly related to the advanced physical and mathematical sciences.
Econtech (2006)	• It evaluated the economic impact of the Backing Australia's Ability (BAA) funding package and found that the productivity gains achieved through the BAA program lead to a long-term increase in real GDP of 0.12 per cent per annum when compared to the counterfactual scenario of no BAA funding. • It also estimated the effect of having public R&D activity versus not having public and found that R&D activity resulted in an increase in real GDP of 1.02 per cent per annum.
Research project or case study approaches	
ACIL Allen Consulting (2014)	• The authors examined the economic impact of CSIRO's research by studying seven case studies within a cost-benefit assessment framework. They conservatively estimated that these case studies have created more than $1.029 billion per annum in value, which exceeds CSIRO's total appropriation.
Allen Consulting Group (2011)	• The authors found that many studies place the social rate of return of public research in the order of 20-50%.
Bloom, Schankerman, and Van Reenen (2013)	• The authors estimated a private rate of return to R&D of 21% and a social rate of return to R&D of 55%.
Deloitte Access Economics (2014)	Deloitte Access Economics conducted four CSIRO case studies and found: • CSIRO's BARLEYmax™ had total economic impacts estimated to be slightly more than $253.3 million per annum. • CSIRO sustainable commercial fisheries research generates $396.1 million per annum of value in the long term. • They find the impacts generated by clinical terminology tools research that is attributable to CSIRO research to be valued at $161.9 million per annum. • They find the impact of research which CSIRO has done in terms of developing tools improve the efficiency of mineral resource exploration which can be attributable to CSIRO research is $444.5 million per annum.
Dowrick (2003)	• The authors surveyed the R&D literature and found gross industry-level returns of up to 40 per cent or more, and gross economy-wide returns of 80 per cent or more.
Econtech (2006)	• The authors found that many studies placed the economy-wide social rate of return on overall publicly funded research in the order of 25 to 40 per cent a year.
KPMG Econtech (2010)	• The authors concluded that most estimates of the rates of return on public R&D are between 20% and 40%.
Scott et al (2001)	• The authors found that recent literature on the returns of public research have ranged from 20-50% and higher.

Source: Deloitte Access Economics

Economy-wide or top-down studies

The economy-wide level of analysis (or "top-down approach") is a group of studies in the literature which uses aggregate data to estimate of the impacts of research activity on total output or productivity in the national economy.

The main methodology used here are macro-econometric studies, which involve the estimation of a production function with knowledge as a key input and variable to the model. More precisely, these studies have sought to estimate of the impacts of changes to either R&D expenditure or the stock of accumulated R&D capital on economic output or productivity, after controlling for the contribution of other inputs such as physical capital and labour.

This sub-section will review some of the existing literature that has provided estimates to this relationship.

Macro-econometric studies

Many Australian aggregate studies confirm the existence of positive returns on domestic R&D (for examples, see Connolly et al, 2004; Louca, 2003; Bodman, 1998; Rogers, 1995; and Dowrick, 1994). The Productivity Commission (2007) provided a range of previous estimates of the responsiveness (elasticities) of output and multi-factor productivity to R&D, and conducted their own estimates of the economic contribution of publicly supported R&D. They found estimates of the responsiveness of GDP or multifactor productivity to a 1% change in R&D, typically fall between 0.05 % and 0.45% Their own estimates found that between 1983 and 2003, the contribution of publicly supported R&D was around $54 billion (in real terms), and $6.5 billion in 2004-2005.

However, to date, there have been very few studies which have examined the role of impact of higher education research on productivity in an Australian context. The main papers which address this topic include:

Burgio-Ficca (2004)

In the Australian university context, Burgio-Ficca (2004) examined the actual performance outcomes of Australian university R&D on Australian state production between 1979 and 1999. The analysis in this paper uses the basic Cobb-Douglas specification of the production function, relating Gross State Product to the inputs used in the production process. The regression results found that higher education R&D has more of an impact on state productivity than the private sector - a 1% increase in the higher education R&D stock leads to a 0.117% increase in GSP. The results indicate that larger coefficients were recorded for the various types of R&D undertaken by the higher education sector compared to R&D undertaken by the private sector.

Elnasri and Fox (2014)

Elnasri and Fox (2014) attempts to have a closer look into some aspects of the Australian innovation system and its impact on the economy. They estimate the relationship between public and university R&D and multi-factor productivity (the efficiency of producers in producing output using both labour and capital). This is distinctly different from Burgio-Ficca (2004) since the focus is on productivity rather than GSP. They found a 1% increase in higher education spending increases multifactor productivity (MFP, the efficiency of producers in producing output using both labour and capital) by 0.305%. Overall, the paper finds evidence of productivity benefits from public spending on Commonwealth research agencies and higher education. However, the results suggest no evidence of spill over effects on private productivity from public support to the business enterprise sector, multisector or defence R&D.

Given that there have been few academic studies in Australia which examine this question; the search is expanded to incorporate some international evidence. To date, most of the recent studies have focused on the United Kingdom and the OECD countries.

Recent studies from the United Kingdom

Haskel and Wallis (2013) reports statistically insignificant results in estimating the relationship between the change in total factor productivity and higher education spending/GDP proportions i.e. share of public R&D spending. Furthermore, they report a negative result in the study which contrasts their 2010 working paper where are positive result was reported.

Haskel and Wallis's 2013 study was updated by Frontier Economics in 2014. Frontier Economics was commissioned by the Department for Business and Innovation and Skills (BIS) to examine the rates of return to investment in science and innovation. Frontier Economics were able to undertake a most extensive analysis of the question by incorporating new research council data. The new data enabled Frontier economics to decompose the effects of research by various research councils on total factor productivity. Higher education research spending as a proportion of GDP was included as part of this analysis and had a coefficient of 48.44. This suggests that a 0.1% increase in spending would increase total factor productivity by around 5%. This result was statistically significant at the 5% level.

It is worth noting that Frontier Economics acknowledges that the coefficients may be large and thus in interpreting the results, the authors have avoided quantifying the impact and left it to the BIS to derive its own conclusions. It states that the magnitude should be interpreted as the strength of the relationship rather than a literal estimate of the social returns.

Guellec et al (2001)

Guellec et al (2001) remains one of the broadest studies to examine the relationship between R&D and productivity. This study presents estimates of the contribution of technical change to multi-factor productivity (MFP) growth in major OECD countries over the 1980-98 period. The analysis was performed at the aggregate (macroeconomic) level for 16 OECD countries over the period 1980-98 using annual data. The dependent variable that the authors used was the change in MFP, and the independent variables were wide ranging and included Business R&D, Foreign R&D Public R&D, R&D intensity, share of public funding, etc.

The key results of this paper were that R&D is important for productivity and economic growth:

- The long-term elasticity of government and university-performed research on productivity is around 0.17. This is much higher than the ratio of public-performed research on business GDP (0.7 per cent to 0.9 per cent in the 1980s and 1990s in OECD), suggesting that overall public R&D is very valuable to the economy.
- The elasticity of public research is higher when the business R&D intensity of the economy is higher. This shows the importance of the business sector being able to seize opportunities raised by public research.
- The elasticity of public R&D is positively affected by the share of universities (as opposed to government laboratories) in public research. This may point to the fact that much government performed R&D is aimed at public missions that do not impact directly on productivity (health, environment), whereas universities are providing the basic knowledge that is used in later stages by industry to perform technological innovation.

It must be noted that there are methodological challenges due the complex causal pathways through which R&D affects productivity, inadequate data across time, measurement errors, varying times lags in benefits of R&D being realised, and difficulties in controlling for the other factors that influence productivity.

Program, university and faculty-level studies

Program, university and faculty-level studies account for the more specific nature of the work of the program, university and faculty. These studies examine a particular research program or portfolio of projects, the research activity of a particular university/research institution (or groups of institutions), or even the activity of a particular faculty.

Theoretically, these studies tend to take a more direct approach towards measuring the impact on the research on the economy. Thus a key strength of these studies is a greater consideration of specific nature of the research. However, the main weakness of these studies is the ability to scale up the impact at a national level. In many cases, it would require restricting assumptions and caveats before the impacts can be reasonably expressed.

Computable general equilibrium (CGE) modelling

A common method for estimating research at this level is computable general equilibrium (CGE) modelling. These studies typically represent research activity as a positive 'shock' to productivity in a CGE model, which flows through the modelled economy, generating estimated GDP impacts. Importantly, an informed judgement is required about the size of the research-related productivity shock that is entered into the model.

For example, using a CGE model known as the CIE-REGIONS CGE model, the Centre for International Economics (2015) estimated that the flow-on and total impacts of advanced physical and mathematical sciences amounted to over 22% of Australian economic activity, or about $292 billion per year. Further, they estimated that 7% of total Australian employment (or 760,000 jobs) is directly related to the advanced physical and mathematical sciences.

Having identified twenty-five measured and verified economic impacts of the CRC Programme, Allen Consulting Group (2005) used the MONASH Multi-Regional Forecasting

(MMRF) model to estimate the economic impact of the CRC programme over the period of 1992 to 2010. They found significant economic benefits, including the result that GDP was cumulatively $1.14 billion higher than would have occurred had the money spent on the CRC Programme instead gone to general government expenditure.

Likewise, using the MMRF model, Allen Consulting Group (2011) examined the combined economic impact of four research institutions within The University of Queensland and computed that in real terms the institutes are expected to increase GDP over the period 1999-2012 by between $3.4 billion and $3.7 billion (in 2005-06 dollars). Further, Queensland GSP was calculated to increase by between $8.2 and $9.0 billion over this same period.

Econtech (2006) examined the impact of public R&D activity on the Australian economy using the MM600+ model. They evaluated the economic impact of the Backing Australia's Ability (BAA) funding package and found that the productivity gains achieved through the BAA program lead to a long-term increase in real GDP of 0.12 per cent per annum when compared to the counterfactual scenario of no BAA funding. Econtech also found that the estimated effect of having public R&D activity versus not having public and found that R&D activity resulted in an increase in real GDP of 1.02 per cent per annum.

Research project or case study approaches

The third and final level of analysis is that of the individual research project. Two common methodologies used here are micro-econometric studies and the case study approach. These studies are tailored to measure the direct impact of a particular research program. Thus the strength of these methods is that they allow for a direct consideration of the impact of a particular research project or program.

However, the weakness of these studies is underpinned by the fact that it provides only a snapshot of the entire universities activities. As a result, the ability to measure the impact of a whole university's research agenda based on a few case studies is limited.

Micro-econometric studies

Micro-econometric studies have sought to estimate and present the benefits of research using a range of measures, such as economic surplus, productivity, and return on investment, willingness to pay, and welfare gains.

Attempts in the literature have consistently shown significant private and spillover benefits of R&D. For example, Bloom, Schankerman, and Van Reenen (2013) used panel data on US firms to identify the technology spill-overs of private R&D, calculating private and social rates of return. They estimated a private rate of return to R&D of 21% and a social rate of return to R&D of 55%.

There is a general consensus in the literature that the total returns to investments in R&D are significant and comprise substantial spillover effects.

- Scott et al (2001), in a survey of the rates of return to R&D commonly found in the literature, found that recent literature on the returns of public research have ranged from 20-50% and higher.

- Dowrick (2003) conducted a similar survey of the R&D literature and found gross industry-level returns of up to 40 per cent or more, and gross economy-wide returns of 80 per cent or more.
- Econtech (2006) concluded that many studies placed the economy-wide social rate of return on overall publicly funded research in the order of 25 to 40 per cent a year.
- KPMG Econtech (2010) concluded that most estimates of the rates of return on public R&D are between 20% and 40%.
- Allen Consulting Group (2011) came to a similar conclusion, that many studies place the social rate of return of public research in the order of 20-50%.

Case studies

The Productivity Commission (2007) has noted that there are only a few detailed Australian cost-benefit studies of university projects. This is because universities concentrate more on curiosity-driven research and applied social research, rather than on large mission-oriented research projects suited to analysis by cost-benefit methods. That being said, there are a large number of case studies done on research institutions such as the CSIRO; and case studies vary in terms of their assessment frameworks - e.g. cost-benefit analysis, cost-effective analysis, cost-consequence analysis, and qualitative appraisals.

ACIL Allen Consulting (2014) examined the economic impact of CSIRO's research by studying seven case studies within a cost-benefit assessment framework. They conservatively estimated that these case studies have created more than $1.029 billion per annum in value, which exceeds CSIRO's total appropriation.

Likewise, Deloitte Access Economics (2014) conducted four CSIRO case studies.

- They find the impact of CSIRO's BARLEYmax™ - a nutritionally enhanced strain of barley - had total economic impacts estimated to be slightly more than $253.3 million per annum once higher farm prices, price premiums for cereal products, and broader health related welfare gains and reduced health system costs were calculated.
- They find the impact of CSIRO sustainable commercial fisheries research generates $396.1 million per annum of value in the long term, as a result of outcomes such as improved ecological outcomes, changes to production value of commercial fisheries and higher recreational value across Commonwealth fisheries.
- They find the impacts generated by clinical terminology tools research that is attributable to CSIRO research to be valued at $161.9 million per annum at maturity as a result of reduced health system costs and imported health outcomes.
- They find the impact of research which CSIRO has done in terms of developing tools improve the efficiency of mineral resource exploration which can be attributable to CSIRO research is $444.5 million per annum at maturity.

In contrast to these quantitative studies, an example of a qualitative case study is Go8 and ATN (2012). This study used expert trial panels to examine 162 research case studies. The panels found that vast majority of case studies (87%) of high quality research carried out in Australian universities has had at least a "considerable" beneficial impact on the health, security, prosperity, cultural and environmental wellbeing of Australia, the region and the world.

Time lags in the practical application and impacts of research activity

It is important to recognise that the knowledge, technologies and innovations generated by research activity do not instantaneously translate into economic benefits. There is typically a time lag between research activity and knowledge creation on the one hand, and uptake by external users and economic impacts on the other. Any estimates of the economic contributions of university research will need to appropriately account for these typical time-lags.

In the three UNSW Faculty of Engineering case studies examined in this report, there were noticeable time lags between when the research activity began and when its economic impacts were observed . In all three cases, the economic value only manifested a number of years after the research projects were conducted at UNSW. In some instances, their economic value is still growing despite the research having begun decades earlier.

This time lag may exist for a number of reasons. For example, there are costs to industry associated with acquiring research output and introducing it to market, such as trial tests, adaption, commercialisation and marketing. Likewise, there may be a lag due to firms slowly becoming aware of the new technology or innovation, and additional time associated with firms adopting it cautiously and incrementally, or only after it has been successfully adopted by other firms.

Given that lags can vary across fields of research, jurisdictions, industry lines and market conditions, ex-ante estimations of the lags involved with individual research outcomes can be highly complex. Similarly, the time lags vary depending on whether the final metric is industry productivity, the emergence of a new product, or some other economic outcome. However, the international economic literature includes aggregate estimates of time lags associated with research of various kinds.

10 years or more

Using the number of academic papers published as measure of knowledge, and estimating this against industry MFP, Adams (1990) finds that there are often long lags between when research is conducted by government or universities and when they influence the marketplace. Adams estimates that there is a time lag of roughly 20 years from when a piece of research knowledge appears in the academic community and when it affects productivity after being absorbed by industry. It is estimated that it takes 30 years for academic science to filter through inter-industry spillovers, while it takes academic technology roughly 10 years to do the same.

6-9 years

On the other hand, Mansfield (1991) finds a shorter time lag for the industrial commercialisation of academic ideas. By examining the time interval between an academic research result and the first commercial introduction of a related product or process across a number of industries, Mansfield concludes that there is an average seven year lag period between research and industrial commercialisation. In an update to the study seven years later, Mansfield (1998) finds that this time lag has dropped to six years, and suggests that this may be the result of closer collaboration between researchers and industry, or because research universities are geared more towards short-term work with quick application times.

In the Australian context specifically, Allen Consulting Group (2005) found that with regards to the CRC Programme, the observed time lags between commencement of a CRC and the achievement of quantifiable economic impacts to be an average of nine years.

5 years or less

Using two independent data sources, Pakes and Schankerman (1984) estimate the average time between project inception and completion ("the gestation lag"), and the time from project completion to commercial application ("the application lag") to be between 1.2 and 2.5 years.

Goto and Suzuki (1989) use survey data to calculate the time lag between R&D and productivity growth in Japanese manufacturing industries. They find that there is a 2 year time lag for industries involved with manufacturing electrical industrial machinery, electronic appliance parts, communication equipment parts and metalworking machinery. They also find a five year time lag for the pharmaceutical industry, and three years for other industries

Park (1995) used a panel of 10 OECD countries from 1970 to 1987 to examine cross-country spillovers of government and private investment in R&D. By setting different lags and using a best-fit strategy, he found that the "peak" lag length was 2 years for private R&D and 3 for foreign R&D. Further, their coefficients increased as the time lags were increased to these two peaks, and then declined.

In their estimate of R&D and productivity growth for OECD countries, Guellec and van Pottelsberghe (2001) set a two year lag for the relationship between productivity and private and foreign R&D. In contrast, they set a three year lag for the relationship between productivity and public R&D, with the rationale being that public R&D is more basic than private R&D and therefore takes longer to affect productivity. These time lags were determined by testing different lags and choosing those that gave the most significant estimates.

Finally, Rouvinen (2002) finds that the effect of domestic private R&D on TFP manifests after a considerable lag, with its effect on productivity to be statistically significant and the largest in absolute terms after around four years.

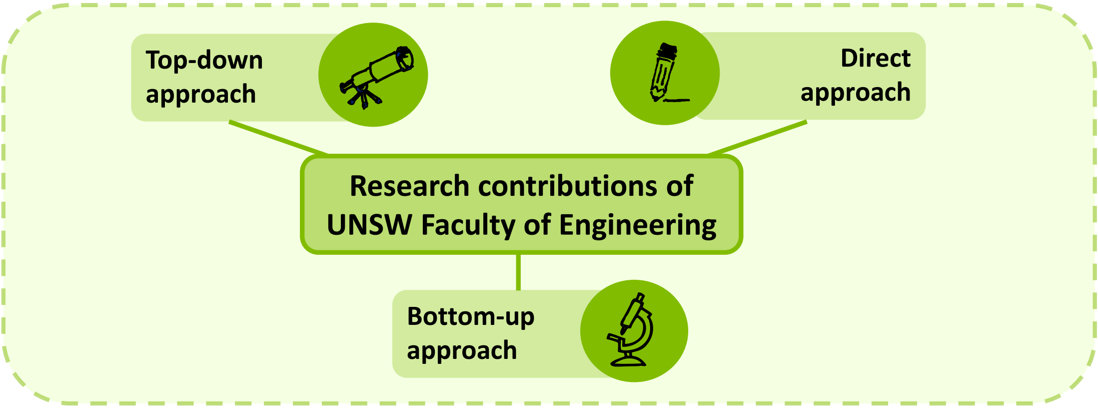
Further, some studies in the literature are inconclusive. Hall et al (1986), for example, fail to find evidence of a time lag in the relationship between R&D expenditure within US manufacturing firms and patent output. Instead, their study suggests that the relationship is strong and contemporaneous.

3.3 Selected approaches

For this study, a combined top-down, direct (faculty-investment) and bottom-up approach was selected to estimate the economic contribution of university research in total, at UNSW, and at UNSW's Faculty of Engineering specifically:

- **Top-down**: involves using macro-econometric analysis of the contribution of total university R&D to productivity and economic growth, which can also be disaggregated for UNSW's research.
- **Faculty-investment (direct)**: involves applying economic multipliers from the R&D literature to the totality of research at the Engineering faculty, to draw inferences about the potential contributions of research at the faculty level.
- **Bottom-up**: involves analysing three specific exemplar research projects in detail, and estimating their direct, indirect, and flow-on contributions.

Figure 3.2: Approaches for estimating the economic contributions of research



Each approach is considered briefly in turn, and then applied in chapter 4.

3.3.1.2 Top-down estimates of contributions

At a macroeconomic level, higher education R&D is considered to be a key driver of economic growth and improvements in productivity (and, subsequently, living standards). The top-down macro-econometric modelling estimates this contribution of university R&D to national productivity and GDP.

We utilise a macro-econometric model – the same as has been used to estimate the impact of higher education attainment – to isolate the effect of research output (defined by aggregate university sector research expenditure) on economic growth over the past 30-40 years. R&D expenditure measures are sourced from the OECD and from the Department of Education. The details of this modelling approach are outlined in Appendix A of this report.

This modelling provides an indication of the effects that university research in Australia, and UNSW's research, has on economic growth. This is achieved by modelling the effects of a change in the level of per capita spending on university research on economic output over a period of time.

3.3.1.3 Faculty-investment (direct) estimates of contributions

Applying economic multipliers from the literature on the impacts of R&D to the totality of research at the UNSW Faculty of Engineering, enables inferences to be drawn about the potential contributions of the Faculty's research, should this knowledge successfully flow through to industry end-use.

Given the relatively experimental and applied nature of research at the UNSW Faculty of Engineering, and examples of collaboration with industry, multipliers from the industry R&D literature are applied judiciously to the totality of the Faculty's research activity.

Broadly, this approach involves:

- examining the international literature on return on private and social returns to investment (ROI) in industry and university research, to find relevant multipliers for engineering research;
- from these results, deriving an aggregate approximate figure of the total potential economic contribution of the UNSW Faculty of Engineering's total research activity to the economy.

This approach involves a strong assumption that historically measured research returns are applicable to research at UNSW's Faculty of Engineering. However, it does enable inferences to be drawn about the potential contributions of the Faculty's research, *should this knowledge successfully flow through to industry end-use*, and can be compared and contrasted against the results of the top-down and bottom-up modelling approaches.

3.3.1.4 Bottom-up estimates of contributions

The bottom-up approach analyses the economic contributions of three exemplar research programs in the Faculty of Engineering in detail, allowing the assessment of their contributions with relatively high confidence.

There is general consensus among academics, professionals in higher education, and professional economists that "bottom-up" case studies exploring the economic contributions of specific research programs in detail produce the most reliable results.

A case study approach can draw on a range of both qualitative and quantitative information, provide rich contextual information, capture heterogeneous outcomes of individual projects, and incorporate a number of economic contributions such as spill-over effects and non-pecuniary impacts.

For these reasons, and in consultation with the UNSW Faculty of Engineering, three high-profile research projects from the Faculty that are well-documented have been selected as case studies:

- **Memtec membrane technology** – a highly effective and relatively low-cost filtration technology utilising hollow nylon fibres, which was invented in the late-1970s.
- **Silicon photovoltaic solar cells** – the development of silicon solar cells with higher levels of efficiency, for the strategic purpose of commercialisation.
- **Kakadu software** – a software development toolkit that is used to create programs which can compress, encrypt and decode certain digital files.

The case studies involve consideration of the attributes of the research (the channels through which knowledge flows, the groups impacted and the different end uses of the technology) to enable a relatively detailed assessment of the associated contributions. To the extent that sufficient data is available on the research projects and economic contributions can be estimated, the results provide a 'lower bound' for the research contributions of the Faculty as a whole.

Chapter 4 applies these three approaches in order to provide a comprehensive and authoritative assessment of the economic contributions associated with the entire gamut of UNSW's activities, with a particular focus on supply-side impacts.

4 Estimates of the economic contributions of UNSW

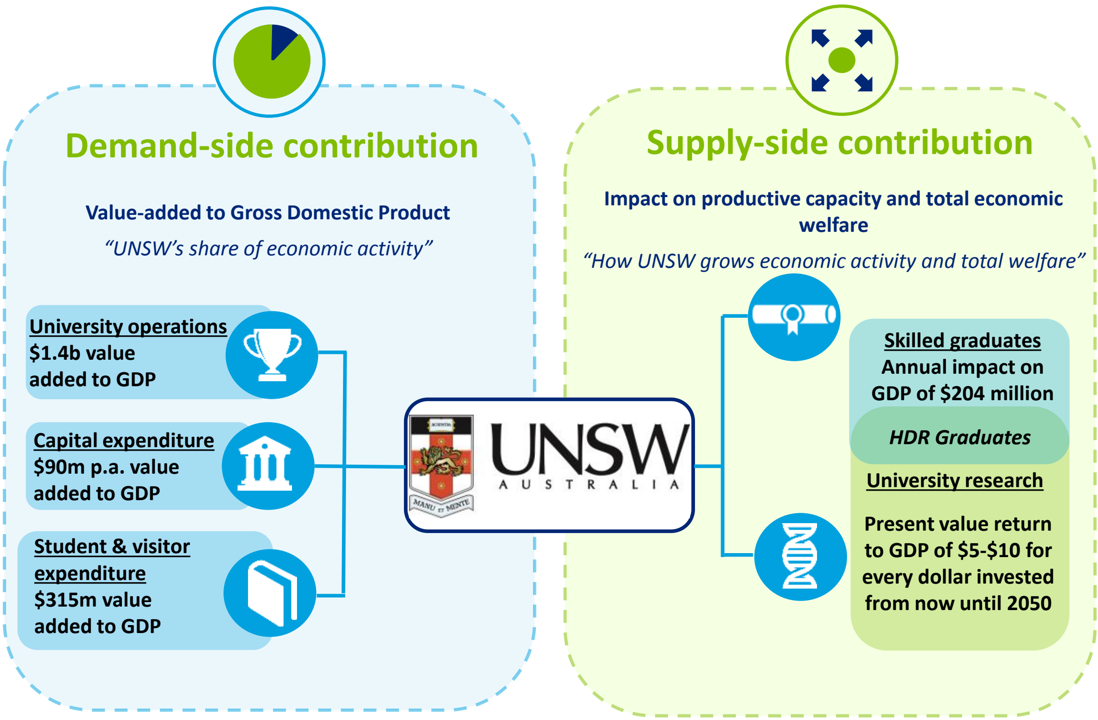
Universities make significant, measurable contributions to their local and national economies. On the demand side, they contribute to economic activity through their ongoing operations, capital expenditure and facilitating student and visitor expenditure. On the supply side, they contribute to productive capacity by increasing the supply of skilled graduates and research on the supply side.

This section reports Deloitte Access Economics' estimates of UNSW's economic contributions in each of these areas and, where possible, the contributions of Australia's universities as whole. Because the demand side measure of contribution comprises an estimate of the current value-added contribution to GDP, whereas the supply side is looking at how the future economic capacity of the economy is enhanced by UNSW, these estimates are not necessarily cumulative, as they rely on different approach to measuring the economic contributions of university activities. Nonetheless, they represent a comprehensive and authoritative assessment of UNSW's economic contributions.

4.1 Summary of contributions

Figure 4.1 below depicts Deloitte Access Economics' estimates of the economic contributions associated with the spectrum of UNSW's major activities.

Figure 4.1: Economic contributions of UNSW



On the demand side:

- UNSW's ongoing operations, student and visitor expenditure in total contributed $1.76 billion to Australian GDP in 2014, including $1.58 billion to GSP in NSW.
    - Of this total $1.76 billion contribution to Australia, over $1.4 billion was contributed by the operations of the university itself, while around $315 million was contributed by students and associated visitors to Australia.
    - By way of comparison, this total contribution to NSW is equivalent to 7% of the total education and training industry output of the state or 12% of the state's mining industry output.
- The equivalent contribution to employment was 11,700 FTE Australian jobs in 2014, including 10,500 in NSW.
- While not additive to the results above, UNSW's average annual capital expenditure from 2012 to 2014 contributed $90 million on average per year to Australian GDP, including $77 million to GSP in NSW.

On the supply side:

- Utilising findings from distinct, but complementary, Australian and international modelling of the *causal* effects of higher education, it is estimated that:
    - university education added $140 billion to GDP in 2014, by raising the productivity of the workforce;
    - by contributing to Australia's stock of higher education human capital, UNSW's 4,900 bachelor degree graduates from 2013 may contribute as much $204 million to Australia's GDP each year over their lifetimes, equivalent to around $41,500 per graduate, as a result of their university education; and
    - UNSW's 8,100 bachelor and post-graduate degree graduates from 2013 will earn, in total, an additional $56 million on average each year over their lifetimes (before tax), compared to what they would have earned with a lower qualification.
- Based on a cross-country macro-econometric model of economic growth, it is estimated that the stock of technology and knowledge attributable to Australia's universities contributed approximately $160 billion to GDP in 2014, almost 10% of total GDP.
    - UNSW's current spending on research represents approximately 9.4% of total research spending by Australian universities.[12] Econometric modelling indicates UNSW's share of the total economic contributions of the stock of technology and knowledge could be in the order of $15 billion.
    - Looking forward, as an illustration of the impact of research universities in Australia, it is estimated that UNSW's current annual expenditure on research of around **$1.04 billion**[13], if sustained over time[14], would:

[12] Source: UNSW data provided for ABS Cat. No. 8111- Survey of Research and Experimental Development Higher Education 2012 and Barlow, The State of Research in Australian Universities, 2015, derived from ABS 8111

[13] Estimate based on above ABS data provided for ABS Cat. No. 8111 and trend approximation of 2014 total spending on R&D nationally. See section 4.3.2 for further detail.

[14] More specifically, sustained year-on-year in real per capita terms.

  - increase GDP by between $106 and $190 billion over a period of 35 years, based on research expenditure of almost $17 billion (both in present value terms);
  - indicate a return for the economy of between $5 and $10 for each $1 invested, over a period of 35 years (in present value terms).
- Drawing upon relevant and defensible estimates from the literature, the expected annual rate of return to the economy of strategic and collaborative university research would likely be between 25% and 40% on average, should the knowledge generated by this research successfully flow through to industry end-use. By way of comparison, the historical expected rate of return on private (business) investment in Australia is estimated to be around 7% per annum. This implies that the gross returns to the UNSW Faculty of Engineering’s 2014 research activity could be between $85 and $95 million.
- UNSW’s research in various areas of engineering, namely membrane filter technology, solar photovoltaic technology and image compression software have generated a range of direct, indirect and flow-on economic contributions.

4.2 Demand-side results

The economic contribution of UNSW’s ongoing operations is a function of the University’s operating revenue and expenses, while the economic contribution of the students and visitors is a function of their expenditure. While not additive to these results, the economic contribution of UNSW’s capital expenditure is a function of expenditure on major items such as buildings and other infrastructure.

The modelling results in this section capture the total economic contribution of UNSW’s ongoing operations and student and visitor expenditure, as well as capital expenditure. This includes all direct expenditure by the University, students and visitors, as well as flow-on contributions to other sectors and regions of the economy.

4.2.1 Economic contribution from ongoing university operations and student and visitor expenditure

UNSW makes large and measurable economic contributions to the UNSW and Australian economies from its ongoing operations, and student and visitor expenditure. These contributions are additive, and demonstrate UNSW’s share of GSP/GDP in 2014.

4.2.1.1 Economic contributions of UNSW’s ongoing operations

The direct economic contributions of UNSW’s ongoing operations are a function of payments to labour (wages) and payments to capital (gross operating surplus). These amounts represent the value added by the university’s labour and capital to inputs to the university’s operations. These amounts are shown in Table 4.1

Table 4.1: UNSW revenue and expenses (NSW campus), 2014 ($m)

	UNSW Total
Operating revenue	1,550
Operating Costs	1,396
Wages	891
Payments to students	97
Other operating costs	408
Gross Operating Surplus	155

Source: UNSW Annual Report, 2014; Deloitte Access Economics

The indirect economic contributions of UNSW's ongoing operations are a function of payments to suppliers. Table 4.2 shows the estimated breakdown for UNSW's payments to suppliers (intermediate inputs) by category and for NSW and Australia.

Table 4.2: Intermediate inputs for UNSW Consolidated, 2014 ($m)

Category	Total	NSW	Australia
Repairs and maintenance	34	19	30
Non-capitalised equipment	45	25	40
Advertising, marketing and promotional expenses	15	8	13
Audit fees	1	1	1
Consumables	34	19	31
Travel and entertainment	45	25	40
Commission to agents	25	14	22
Contract services (including consultants)	143	79	128
Cost of books sold	6	3	5
Energy, utilities, postage and telephone	24	13	21
Fees, charges and insurance	32	18	28
Operating lease expenses	12	7	11
Other operating expenses	15	8	14
Total intermediate inputs	**431**	**239**	**385**

Source: UNSW Annual Report, 2014; Deloitte Access Economics
Notes: The total figure includes spending by both ADFA and UNSW. The NSW figure has been adjusted downwards to account for: (1) only suppliers based in NSW; and (2) ADFA spending in the ACT. The Australia figure includes ADFA spending.

In 2014 UNSW contributed a total of $1.22 billion to the economy of NSW, from its ongoing operations, including all direct and indirect effects (Table 4.3).

Table 4.3: Contribution of UNSW to NSW, 2014 ($m)

Contribution	UNSW
Total direct contribution	1,046
Wages	891
GOS	155
Total indirect contribution	170
Wages	96
GOS	74
Total contribution	**1,216**

Source: UNSW Annual Report, 2014; Deloitte Access Economics

The total economic contribution of UNSW's ongoing operations to the Australian economy in 2014 was $1.44 billion. The economic contributions in NSW and Australia in terms of FTE employment were 7,163 and 8,745 respectively.

Table 4.4: Total contribution of university operations, 2014

Contribution	NSW	Australia
Total direct contribution ($m)	1,046	1,106
Total indirect contribution ($m)	170	338
Total contribution ($m)	**1,216**	**1,444**
Total direct employment (FTE)	5,895	6,232
Total indirect employment (FTE)	1,268	2,513
Total employment (FTE)	**7,163**	**8,745**

Source: Deloitte Access Economics estimates

4.2.1.2 Student and visitor expenditure

UNSW attracts thousands of students into NSW from interstate and overseas. In 2014, more than a third of UNSW's students were in this category (Table 4.5).

Table 4.5: Onshore UNSW students by home location, 2014

Type	NSW	Interstate	International
Undergraduate	22,957	2,251	5,607
Postgraduate Coursework	7,452	2,072	4,549
Postgraduate Higher Degree Research	2,091	428	1,558
Non-award	N/A	N/A	2,564
Foundation	N/A	N/A	2,474
Total	**32,500**	**4,751**	**16,752**

Source: UNSW data, 2014

The interstate and international students attracted to NSW to study at UNSW spend money on a range of goods and services; with this expenditure being 'additional' to the economic activity that likely would have occurred in the absence of UNSW. The average expenditure of these students differs depending on the level of their study and residency status (Table 4.6).

Table 4.6: Average annual student expenditure off campus, 2014 ($)

Student Type	Weighted average of full-time and part-time students
Domestic	
Undergraduate	28,120
Postgraduate Coursework	38,680
Postgraduate Higher Degree Research	38,895
International	
Undergraduate	21,352
Postgraduate Coursework	24,250
Postgraduate Higher Degree Research	29,567

Source: Universities Australia, Deloitte Access Economics estimates

Notes: Off campus spending excludes categories that would be counted under the university's revenue (e.g. accommodation, HECS repayments, sports and union fees, university fines and fees etc.). International student spending has been adjusted for NSW state characteristics – it is 4% higher than the figure reported in the Universities Australia report. Non-award students get 12/52 weighting of the average international student, and foundation students get 0.53 weighting, in light of the typical duration of their courses.

In total, UNSW's interstate and international students spent $498 million in NSW in 2014. International students spent an additional $20 million in the rest of Australia (Table 4.7).

Table 4.7: Total annual student expenditure off campus, 2014 ($m)

Expenditure	NSW	Rest of Australia
Interstate	160	N/A
International	338	20
Total	**498**	**20**

Source: Universities Australia, Deloitte Access Economics estimates

Note: Australia international figure adjusted up to include international students in ADFA.

The economic contribution of additional UNSW student expenditure in NSW was $358 million in 2014, equating to employment of 3,426 FTE (Table 4.8).

Table 4.8: Contribution of additional student expenditure, 2014 ($m)

Contribution	NSW
Total contribution ($m)	**358**
GOS ($m)	160
Labour Income ($m)	197
Total employment (FTE)	**3,426**

Source: Deloitte Access Economics estimates

International and interstate students often host visiting friends and relatives (VFR), who bring further expenditure into NSW. Expenditure by UNSW VFRs in NSW totalled $4 million in 2014 (Table 4.9).

Table 4.9: Total additional visitor expenditure by region, 2014 ($m)

Expenditure	NSW	Rest of Australia
Interstate	2	N/A
International	3	4
Total	**4**	**4**

Source: TRA, Deloitte Access Economics estimates

Note: Australia international visitors includes those visiting ACT for ADFA international students

The economic contributions associated with the expenditure of VFRs totalled $3.2 million, or 37 FTE, in 2014 (Table 4.10).

Table 4.10: Contribution of additional visitors by region, 2014

	NSW	Rest of Australia
Expenditure ($million)	**4.5**	**4.4**
GOS	1.3	1.5
Wages	1.9	2.2
Total value added ($million)	**3.2**	**3.7**
Total employment (FTEs)	**36.7**	**36.4**

Source: Deloitte Access Economics estimates

4.2.1.3 Total economic contribution

In total, the ongoing operations of UNSW, and the expenditure of its students who move to the region to study and their visitors, contributed approximately $1.57 billion (equivalent to 10,600 FTE jobs) to the NSW economy in 2014 (Table 4.11).

Table 4.11: Additional contribution of UNSW to NSW, 2014

	University	Students	Visitors	Total
Revenue/Expenditure ($ million)	**1,550**	**498**	**4**	**2,053**
Value added ($ million)				
Direct	1,046			1,046
Indirect	170	358	3.2	531
Total	**1,216**	**358**	**3.2**	**1,577**
Employment (FTE)				
Direct	5,895			5,895
Indirect	1,268	3,426	36.7	4,731
Total	**7,163**	**3,426**	**37**	**10,626**

Source: Deloitte Access Economics estimates

Nationally, the ongoing operations of UNSW and the expenditure of its students and visitors contributed approximately $1.76 billion (equivalent to 11,700 FTE jobs) to the Australian economy in 2014 (Table 4.12).

Table 4.12: Additional contribution of UNSW to Australia, 2014

	University	Students	Visitors	Total
Revenue/Expenditure ($ million)	**1,639**	**358**	**4**	**2,001**
Value added ($ million)				
Direct	1,106			1,106
Indirect	338	315	3.7	657
Total	**1,444**	**315**	**3.7**	**1,763**
Employment (FTE)				
Direct	6,232			6,232
Indirect	2,513	2,932	36.4	5,481
Total	**8,745**	**2,932**	**36**	**11,713**

Source: Deloitte Access Economics estimates

4.2.2 Economic contribution from capital expenditure

The economic contributions of ongoing university operations include those generated by existing capital such as buildings and infrastructure. This shows up in a university's gross operating surplus, which is interpreted as payments to capital. However, **new major capital expenditure** undertaken by universities will not yet show up in the operating statement, but can have significant **one-off economic impacts**, boosting construction activity and related industries. In light of this, Deloitte Access Economics ran UNSW's recent major capital expenditure through its input-output model to assess the potential contributions associated with capital investment.

UNSW spent an average of $122 million per year on major capital expenditure over the last three years (Table 4.13).

Table 4.13: UNSW Major Capital Expenditure, 2012-14 (2014$m)[15]

	2012	2013	2014	Average
Expenditure in NSW	133	113	122	122
Expenditure in Australia	194	168	185	183
Total expenditure	**216**	**189**	**208**	**204**

Source: UNSW data, Deloitte Access Economics estimates

Note: only includes capital expenditure on land and buildings.

While not additive to the results in section 4.2.1, UNSW's average annual capital expenditure from 2012 to 2014 contributed $90 million on average per year to Australian GDP, including $77 million to GSP in NSW (Table 4.14).

[15] While the majority of capital expenditure is made within Australia some will be imported from overseas, estimated in this instance to be around 10% of total spending.

Table 4.14: UNSW Indirect contribution of capital expenditure by region, 2014

	NSW	Australia
Expenditure ($m)	**122**	**183**
Total indirect contribution ($m)	**77**	**90**
GOS ($m)	36	42
Wages ($m)	41	48
Total indirect employment (FTE)	**494**	**580**

Source: UNSW data, Deloitte Access Economics estimates

4.3 Supply-side results

4.3.1 Skilled graduates

The economic contributions associated with skilled university graduates are observable in the wage premiums (and higher employment) experienced by graduates, as well as the impacts they have on the productive capacity (ability to produce more from the same or less inputs) of the economy.

Two measures of the economic contribution of UNSW's teaching and learning are considered in this study. The first measure is the contribution of UNSW graduates' in term of embodied human capital to Australia's economic output. The second is the returns to individual graduates from UNSW in the form of higher lifetime earnings (a component of the total economic contribution).

4.3.1.1 The total economic contribution of UNSW's skilled graduates

Our modelling extends the neo-classical Solow growth model adopted by Mankiw et al (1992) by incorporating tertiary human capital as an additional input in the aggregate production function. In this model, economic output is a direct function of factor inputs: physical capital, labour, tertiary human capital and the Solow residual. The Solow residual or total factor productivty (TFP) drives technological progress or the productivity of these factor inputs.

This modelling approach focuses on the effects of higher education, by considering the percentage of population completing higher education as an indicator of the total stock of tertiary human capital in the economy. By explicitly controlling for tertiary human capital in the growth equation, the effects of other forms of education such as primary, secondary, and work experience are implicitly incorporated within the residual (TFP). This allows us to isolate the causal effects on economic growth resulting from increased higher education attainment. Further details of the modelling approach and the associated econometric results can be found in Appendix A of this report.

Overall, the modelling results suggest a significant impact of tertiary human capital on output per capita across countries and over time. The implied share of human capital to output per capita is between 8.36% and 16.02%. For Australia this translates to between $136 billion and $261 billion of GDP in 2014, or an average of almost $200 billion.[16]

Furthermore, the results from our modelling also indicate that a persistent 1.9 percentage point increase in tertiary education completion rates (a 10% increase from the 2010 level in Australia) among Australia's population would lead to an average increase in steady state output per capita (GDP per capita) of 1.52% to 2.33%.

In 2013, around 70% of tertiary education attainment in Australia was in higher education qualifications at a bachelor level and above (AQF levels 7-10), which are predominately

[16] It should be noted that tertiary education includes ISCED levels 5-8, i.e. Higher education Diplomas and above. As not all of these qualifications are obtained through the university system in Australia it likely overstates the total share of the contribution of university higher education human capital stock to economic output.

undertaken at university.[17] This implies that a conservative[18] value of the contribution made by university higher education to GDP in 2014 is 70% of $200 billion, or $140 billion.

It is therefore estimated that university education added $140 billion to GDP in 2014, by raising the productivity of the workforce.

In 2013, UNSW had 4,901 domestic students graduate with a bachelor degree. If we assume that these students would not have attained a tertiary education qualification had they not attended UNSW then it is possible to estimate the implied effects of their graduation on total higher education attainment in Australia.[19]

In 2014 this population of graduates would comprise 0.1% of the population of Australians with tertiary education qualifications (estimated to be 21% of the *total* Australian population in 2014). Applying this to the 2014 share of economic output attributable to higher education human capital, their contribution would be equivalent to **approximately $204 million in real 2014 dollars, or around $41,500 per graduate (each year)**.[20]

Importantly, this $204 million contribution to GDP would not occur immediately in 2014, but rather would be contributed, each year on average, over the course of the lifetimes of the skilled graduates. Using the 2014 share of output as an estimate of this long-term contribution relies on the assumption that the human capital stock in Australia grows in proportion to the economy as a whole over the long term, and so in real terms the average contribution of these skilled graduates remains constant (in average terms).

Limitations

This assumption may be unrealistic if diminishing returns to the accumulation of human capital are present. However, it is consistent with the interpretation of the long-run steady state model of economic growth implied by our macro-econometric growth model. In this model, human capital accumulation is a primary contributor to living standards growth, the share of which remains stable over time.

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[17] Source: UNESCO educational attainment data by ISCED category, 2013. http://data.uis.unesco.org/

[18] In principle, the impact from higher level educational qualifications will be greater than that for lower qualifications. So applying the estimated 70% of total tertiary educational attainment which is defined as higher education may understate the contribution of these qualifications.

[19] This may be an unrealistic assumption if the contribution of UNSW is considered in isolation to other universities in Australia, who may also have provided these students with higher education qualifications. However, this particular estimate is intended to illustrate the total contribution of tertiary education in Australia and the share of the contribution attributable to UNSW. In this sense the contribution analysis is not considering the counterfactual of how many students would have studied at other university in the absence of UNSW.

[20] Implicitly this assumes that the human capital embodied by UNSW bachelor degree graduates is representative of the average value of the human capital stock pre-existing in the population. While this may be an unrealistic assumption it is not possible to determine directly whether it comprises an over or underestimate of their contribution. Firstly because the human capital associated with a bachelor degree may fall above or below the average embodied by stock of individuals with a higher education and that the value of (gained) human capital embodied by UNSW skilled graduates may exceed the average for universities in Australia as a whole (as implied by Wilkins, 2015). On the other hand, the stock of human capital held by existing graduates would include a proportion with post-graduate qualifications, reflecting higher levels of human capital.

Further, it should be noted these estimates comprise the gross benefit associated with increased higher education attainment resulting from graduates from UNSW and do not consider the economic costs associated with their education, including the resource costs associated with the activity of teaching and learning and the opportunity costs of forgone time in the labour force while studying.

Benefits not captured

While this estimate provides an indication of the contribution domestic bachelor graduates from UNSW make to the economy as a whole, it does not include:

- The contribution made by the 3,191 domestic post-graduate course work and higher degree research students who graduated from UNSW in 2013.
  - Post-graduate students do not technically contribute to the higher education attainment level of the nation as defined in our econometric model, as they already (in general) have an existing higher education qualification (e.g. a bachelor degree). However, as a result of their further education, these graduates would certainly make a significant contribution to economic output, as indicated by the additional wage premiums that they earn. This contribution is discussed further in the following sections of this report.
- The contribution to the human capital stock of Australia made by the 4,113 international undergraduate and post-graduate students who completed a degree at UNSW in 2013.
  - It is not possible to determine the proportion of international student graduates from UNSW who go on to live and work in Australia, and thereby contribute to the nation's level of higher education attainment. Further still, this process is generally determined by the Australian skilled migration system, wherein international student graduates from higher education in Australia may displace skilled migrants with higher education obtained overseas.
  - However, even when an international student returns to their origin country following their study in Australia, they can provide significant contributions to the Australian economy through enhanced cultural and economic ties. As Australia increasingly relies on trade with Asia to support its ongoing prosperity, building strong and lasting connections with Asia will be critical to support trade, diplomacy and international business. International students in Australia, who return to their origin country following their study, play an important role in facilitating these connections.
- The contribution made by non-completing higher education students at UNSW.
  - While students who do not complete their enrolled degree at UNSW do not increase the level of higher education attainment in Australia, they will still make contributions to the economy as a result of the skills, knowledge and expertise that they acquired during the time enrolled at UNSW.

4.3.1.2 Estimates of benefits to graduate lifetime earnings

Students gain a variety of skills over the course of their degrees, resulting in the development of human capital. Graduates are then equipped with the knowledge necessary to contribute successfully in their chosen fields, and will experience benefits relating to income and earnings over the course of their career. These are termed private market benefits, as they accrue privately to the individual student and are measured in the marketplace through increased wage earnings from higher education qualifications. These private market benefits comprise part of the total economic benefits from higher education attainment.

A recent study of the Household, Income and Labour Dynamics in Australia (HILDA) Survey found that individuals receive significant returns from higher education in Australia in the form of an increased likelihood of being employed full-time and receiving higher weekly income. These results are determined after controlling for demographic factors and cognitive ability (Wilkins, 2015).

> *The addition of these controls arguably provides a stronger basis for interpreting estimates for education variables as 'causal', on the grounds that this controls for the higher innate ability of the more-educated that would suggest they would have better labour market outcomes even without the additional education. Nonetheless, the estimates should at best be regarded as tentative evidence of the causal effects of education. (Wilkins, 2015, pp. 70-71).*

The results from this analysis are included in Table 4.15 below.[21] Income returns from each level of higher education are measured relative to the average income of individuals with education levels equivalent to year 11 or below. Employment effects are measured in decimal points of the probability of employment (or full-time employment) attributable to each higher education qualification level. For example, women with a bachelor degree are 6 percentage points more likely to be employed than those with education levels equivalent to year 11 or below.

Table 4.15 : Returns to higher education in Australia (2012)

	Probability of being employed		Probability of being full-time employed		Weekly earnings premium of full-time employees	
	Males	Females	Males	Females	Males	Females
Postgraduate Degree Level	0.04	0.04	0.09	0.08	49%	40%
Graduate Diploma and Graduate Certificate Level	(0.01)	0.06	0.05	0.05	45%	33%
Bachelor Degree Level	0.01	0.06	0.03	0.03	42%	32%
Advanced Diploma and Diploma Level	0.03	0.07	0.07	0.10	28%	8%
Certificate 3 or 4	0.03	0.11	0.06	0.03	20%	0%
Year 12	0.00	0.06	0.01	0.05	19%	14%

Source: Wilkins (2015) corrected version of Table 7.4. Figures marked red are *not* statistically significant at the 10% level.

[21] These results are obtained from a corrected version of Table 7.4 in the original Wilkins (2015) report. Wilkins released these corrections in an erratum on 16 September 2015 (https://www.melbourneinstitute.com/hilda/Reports/statreport.html).

Using the results presented above it is possible to estimate the causal impact of higher education on earnings for skilled graduates at UNSW. This is achieved by applying the HILDA estimates of the employment and earnings 'premiums' of higher education to the observed earnings and employment levels of the population of workers in Australia by level of educational qualification, drawn from the ABS 2011 Census.

Total Personal Income (weekly) (INCP) data is used to calculate average weekly earnings.[22] While this is an imperfect measure of earnings (as it includes both wage and non-wage income) it is the most detailed and comparable estimate of earnings available that is relatively comparable to the data used in the HILDA survey to estimate the effects of education outlined above.[23]

For simplicity we take a year of UNSW domestic graduates at an undergraduate and postgraduate level and assume that their full-time employment status conforms to the population average for individuals with that level of educational qualification (as determined by the 2011 ABS census), as shown in Table 4.16. For example, we assume that of the 1,389 female postgraduate degree level graduates in 2013, approximately 701 will be full-time employed (on average over the course of their lives) and of those full-time employed, they will have average weekly earnings of $1,741 (in 2014 dollars).

Combined, these 8,092 skilled graduates, of which around 4,678 are assumed to be employed full-time (on average, over the course of their life), earn gross income of just over $434 million (in 2014 dollars) per year. Earnings estimates have been converted to 2014 dollars based on the average wage price index for all industries in Australia.[24]

Table 4.16 : Earnings and employment outcomes by educational qualification level, 2011 ABS Census (2014 dollars)

	Probability of being full-time employed (ABS 2011 census)		Weekly earnings of full-time employees (ABS 2011 census)		Full-time employed population (2013 UNSW Graduates)		Population (2013 UNSW Graduates)	
	Males	Females	Males	Females	Males	Females	Males	Females
Postgraduate Degree Level	69%	50%	$2,027	$1,741	1,248	701	1,802	1,389
Bachelor Degree Level	68%	44%	$1,825	$1,465	1,673	1,056	2,479	2,422
Year 12	46%	25%	$1,205	$1,008	-	-	-	-
Year 11 and below	34%	14%	$1,088	$924	-	-	-	-

Source: ABS Census, 2011; Department of Education Ucube statistics

Applying the causal estimates from Wilkins (2015) it is possible to estimate the total earnings of these skilled graduates had they obtained a lower level qualification (year 12 for

[22] Average wages for different groups are calculated using imputed median incomes provided by the ABS: http://www.abs.gov.au/websitedbs/censushome.nsf/home/factsheetsuid?opendocument&navpos=450

[23] Because the effects of higher education are measured in relative terms, the effect of using income rather than wage data will likely be small, particularly as there is little discrepancy between these series on average.

[24] ABS Cat no. 63450 Quarterly Index ; Total hourly rates of pay including bonuses ; Australia ; Private and Public ; All industries ; June 2011 (108.2) to June 2014 (118.2).

bachelor graduates, or a bachelor degree for post-graduate students). This is achieved by subtracting the percentage point differences in full-time employment probabilities and wage premiums between individuals with a bachelor degree and year 12, and between those with a postgraduate degree and bachelor degree. The results of this counterfactual scenario are detailed in Table 4.17 below.

Table 4.17 : Expected earnings and employment outcomes of a lower level qualification (counterfactual scenario), 2011 ABS Census (2014 dollars)

	Probability of being full-time employed (ABS 2011 census)		Weekly earnings of full-time employees (ABS 2011 census)		Full-time employed population (2013 UNSW Graduates)	
	Males	Females	Males	Females	Males	Females
Postgraduate Degree Level	63%	45%	$1,945	$1,666	1,136	622
Bachelor Degree Level	66%	46%	$1,576	$1,300	1,636	1,114

Source: ABS Census, 2011; Department of Education Ucube statistics; Deloitte Access Economics estimates from Wilkins (2015)

As demonstrated by these results, less than half of the observed difference in earnings between those individuals with just year 12 and those with a bachelor degree level of education is explained by the contribution of the qualification itself, with over half explained by other factors, such as age, experience, demographic characteristics (such as parental education and occupation) and innate cognitive ability.

In this counterfactual scenario, the total gross wage income per year earned by UNSW skilled graduates is approximately $378 million (in 2014 dollars). Subtracting this from the original $434 million results in an estimated annual gross wage benefit of around **$56 million** (in 2014 dollars).

These estimates, like those for the total economic contribution of skilled graduates, are representative of the average annual returns accrued to these skilled graduates over the course of their lives. Further, they represent the *gross* wage benefits from higher education. The estimates do not account for the additional tax paid as a result of higher average income, which would not be captured as a benefit to the student but rather as additional income to the government. They also do not account for the opportunity cost of obtaining the higher education degree qualification, both in terms of tuition fees and forgone earnings while studying. Nonetheless, these estimates demonstrate highly favourable returns to investments in higher education on average, similar to those found by Corliss et al (2013) and Leigh (2008).

Limitations

There are a number of limitations to this analysis that influence the reliability of the estimates. Some of these limitations may, in isolation, lead to an underestimate of the returns to higher education, while others may lead to an overestimate.

Key limitations include:

- the benefits of higher education to full-time workers may be overstated: the estimates rely on ABS Census data from 2011 which only covers full-time employment. The counterfactual scenarios suggest that a proportion of individuals would no longer be employed full-time if they had a lower qualification. While true, the analysis assumes that these individuals would simply earn no income, rather than earning part-time or casual wages. The effects of higher education on full-time employment and total income will be overstated to the extent that some of these individuals would earn part-time or casual incomes (rather than none at all) if they held a lower qualification.
- the benefits of higher education overall may be overstated: in some cases the analysis utilises estimates of the effects of higher education on full-time employment that, while material in size, are statistically insignificant (and are therefore not highly reliable).
- the benefits of higher education overall may be understated: the analysis just captures the benefits of higher education to UNSW graduates who work full-time, and not the additional earnings of UNSW graduates who work casually or part-time, or who are self-employed.

On balance, these estimates likely represent an *underestimate* of the earnings and employment benefits of UNSW's skilled graduates. In particular, only the wage and employment benefits associated with *full-time* work are included. Income benefits associated with entrepreneurship and ownership of business are also not captured.

Finally, it should be noted the contribution estimates provided here are not unique to UNSW graduates; they apply to higher education graduates in general. There is reason to believe that these contributions are likely an underestimate of the contribution that UNSW makes to its graduates. As a top university in NSW, UNSW attracts some of the brightest and most talented students, and may provide above-average wage and employment outcomes for its students.

Benefits not captured

Other non-market and non-monetary benefits from higher education are also not captured; including factors such as higher levels of health and life satisfaction. Recent international analysis has shown the monetary value of non-market benefits may be equivalent in magnitude to the market benefits that students receive (McMahon, 2009).

4.3.2 Research contributions

This section reports the results of the combined top-down, direct (faculty-investment) and bottom-up approaches selected to estimate the economic contribution of university research in total, at UNSW, and at UNSW's Faculty of Engineering specifically. These include:

- **Top-down**: involves using macro-econometric analysis of the contribution of total university R&D to productivity and economic growth, which can also be disaggregated for UNSW's research.

- **Faculty-investment (direct)**: involves applying economic multipliers from the R&D literature to the totality of research at the Engineering faculty, to draw inferences about the potential contributions of research at the faculty level.
- **Bottom-up**: involves analysing three specific exemplar research projects in detail, and estimating their direct, indirect, and flow-on contributions.

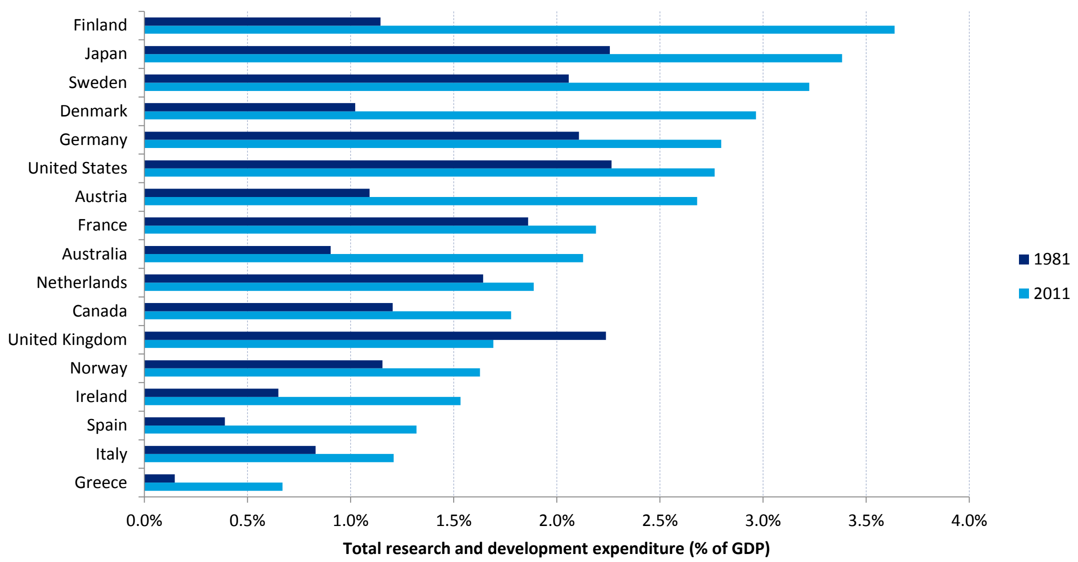
4.3.2.1 Top-down estimates of contributions

As noted in the estimates of contribution of skilled graduates to economic output, our modelling extends the neo-classifical Solow growth model adopted by Mankiw et al (1992) by incorporating tertiary human capital as an additional input in the aggregate production function. In this analysis of the determinants of growth also include research and development (R&D) activities.

It is well recognised that the productivity benefits from research and successful innovations are not fully absorbed by the innovating entities but, rather, they diffuse through the rest of the economy leading to positive externalities in growth and the productivity performance of other using entities. Expenditure on R&D can be considered as an investment in knowledge stock that translates into new technologies as well as more efficient ways of utilising existing resources such as physical capital, human capital, and labour.

Overall expenditure on R&D as a share of GDP has risen since the 1980s in most countries (Figure 4.2). This has mainly reflected increases in R&D activity in the business sector that accounts for the majority of expenditure in this area in most OECD countries (Bassanini and Scarpetta, 2001).

Figure 4.2: Total research and development expenditure, selected countries, 1981 - 2011



Source: Deloitte Access Economics, The World Bank

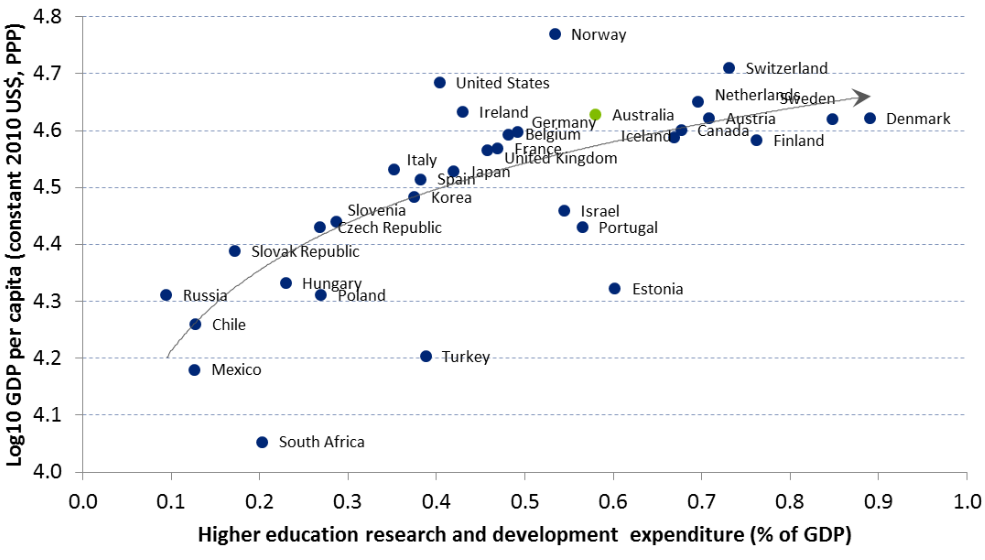
The effect of knowledge capital on productivity may work through various channels depending of the source of the knowledge. For example, R&D can be performed either by the business sector, higher education institutions or public sector agencies. Each of these types of R&D performers can be a source of significant domestic technological change. R&D performed by the business sector results in new goods and services, higher quality of output, and new production processes. In comparison, R&D performed by higher education institutions enhances the stock of knowledge available for the society, it may open new opportunities for business research, which in turn might improve productivity. Regardless of the exact relationship between the sources of R&D, it is clear that any quantitative analysis of growth must take R&D activity into account as an additional form of investment and differentiate between various types of R&D entities (Elnasri and Fox, 2014).

In this research, given data availability, we consider total R&D expenditure (as a share of GDP) and its two components, higher education and non-higher education sector R&D expenditure.

The economic contributions of research in Australia

Our modelling results support previous evidence suggesting a significant effect of R&D activity on the economic growth process. In particular, we show the elasticity of higher education R&D per capita to output per capita to be between 0.175 to 0.184. That is, a *persistent* 10% increase in Australia's university R&D spending per capita would have a long-run effect of about 1.75% to 1.84% higher output per capita. This relationship is illustrated in Figure 4.3 which shows the relationship between higher education R&D spending as a proportion of GDP and per capita income.

Figure 4.3: University research and per capita income across countries



The estimates produced by this model can be used to estimate the long-run contribution of the stock of knowledge generated by Australian universities to the Australian economy. This share of output is estimated to be around 10% of GDP in the economy's steady state, which is equivalent to around $160 billion in 2014. This represents the contribution of historical investments in research made by Australian universities. By way of comparison, this contribution exceeds the entire value of Australia's mining industry.

The size of this impact is substantial, perhaps even unreasonably so. Nonetheless, the effect sizes are consistent with results from other studies both in Australia and overseas and point to significant positive economic spillovers from university research expenditure.

A detailed explanation of the model and its results is included in the appendix of this report.

The economic contributions of UNSW research in Australia

The most recent available estimate of total spending by Australian universities on R&D is $9.6 billion for the year 2012.[25] In that year, it is estimated that UNSW contributed around 9.4% of this spending, representing a total of around $902 million.[26]

Through the use of a (cubic-spline) extrapolation of this dataset (on R&D expenditure at Australian universities provided by the ABS) the total spending by Australian universities on R&D is estimated to have been around $11.1 billion in 2014. By applying the share of R&D expenditure attributable to UNSW in 2012 to this figure it is estimated that UNSW spent a total of $1.04 billion on R&D in 2014.[27]

If it is assumed that UNSW's share of the total long-run contribution of the stock of knowledge generated by Australian universities to the Australian economy ($160 billion in 2014) is commensurate to UNSW's most recent share of expenditure on university R&D (9.4% in 2012), then its contribution would be equivalent to around $15 billion in 2014. However, it should be noted that, historically, this share of total university R&D expenditure likely represents an underestimate of UNSW's share of the existing stock of knowledge attributable to Australian university research.

Looking forward, it is possible to use the estimated elasticity effects of university research expenditure per capita on GDP per capita to estimate the impact that UNSW's current annual expenditure on research of around $1.04 billion would have on the economy relative to a scenario where that research expenditure did not occur.

In 2014, UNSW research expenditure was $1.04 billion. If this spending did not occur, a 9.7% change in total national university research expenditure relative to 2013 levels would result. Using the estimated elasticities from our macro-econometric model, a 9.7% change in national university R&D per capita is associated with a long-run impact on economic output of around 1.73% of national GDP. That is, a persistent increase (decrease) in real R&D spending per capita of 9.7% results in an increase (decrease) in long-run steady state level of real GDP per capita of around 1.73%.

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[25] Source: ABS 8111- Survey of Research and Experimental Development Higher Education 2012

[26] Source: UNSW data provided for ABS 8111- Survey of Research and Experimental Development Higher Education 2012 and Barlow, The State of Research in Australian Universities, 2015, derived from ABS 8111

[27] It should be emphasised that this figure relies on the trend extrapolation of national spending on R&D described above. As a result it will likely differ from the actual R&D spending by UNSW in 2014 (details of which will be made available in the next ABS Cat. No. 8111 report due in late 2016). Further, it should be noted that while the estimates included here are consistent with the ABS and OECD methodologies for calculating university R&D expenditure, they incorporate substantial indirect research costs and other expenses which in other circumstances may not be included in measures of research spending at a university level.

The effects of this increase in GDP will take place over time, due to both time-lags associated with the effects of research output on productivity and as the economy transitions to its new level of economic output caused by this productivity improvement.

As outlined in section 3.2.2.2 of this report, there are a wide range of estimates in the international literature on time lags, most of which fall within a 5-20 year range. To motivate the analysis here two possible scenarios are considered: a short-term scenario where research activity affects economic productivity after 7.5 years and a long-term scenario where the effects only manifest after 15 years. The existence of potentially lengthy time lags is supported by the observations this report has made regards to its three UNSW research case studies – Memtec membrane, photovoltaics and Kakadu software.

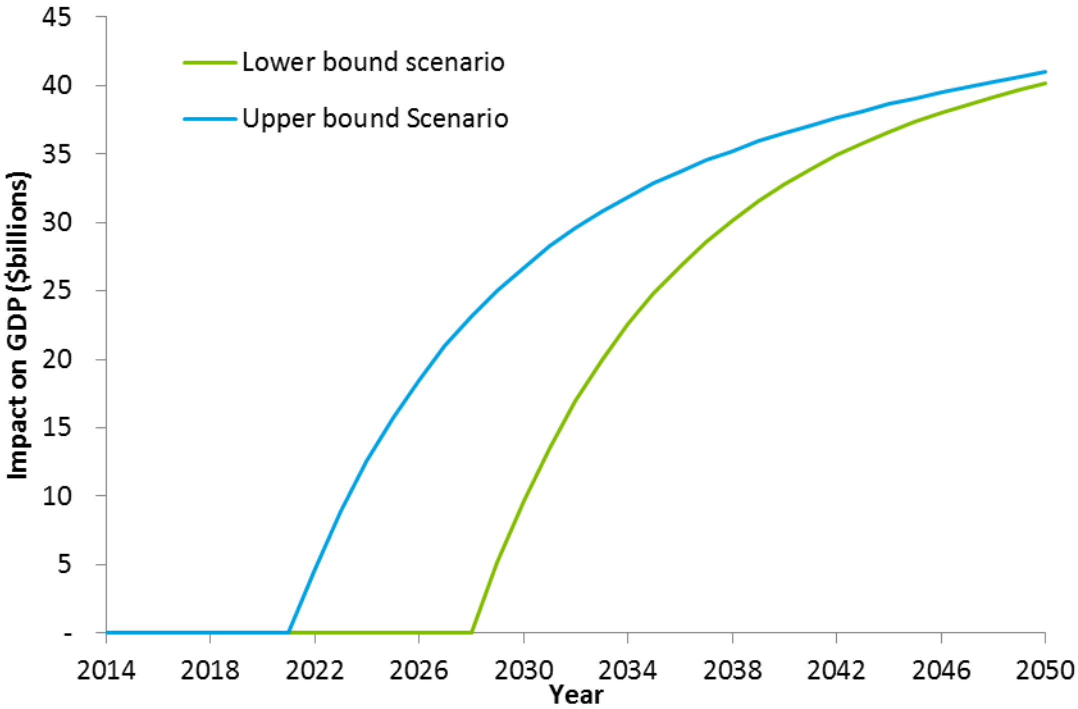
The timing of how these productivity effects are realised in terms of output are governed by the transition dynamics of the economy; that is, how the economy responds to productivity effects through the accumulation of capital inputs. These transition effects can be approximated through the use of the convergence term that is estimated in the econometric growth model.

The convergence term in our model is estimated to be 0.149, which indicates that the economy will close 14.9% of the gap between the current level of output and steady-state output each year following a change to the exogenous parameters of the model (in this case, the productivity impact of an increased level of university R&D spending per capita). It should be noted that the convergence process is asymptotic, meaning that countries will never truly reach their steady-state levels but rather move very close to it.

Applying the lag-effects of spending on university research and the convergence term for the economy described above, it is possible to estimate the impact on long-run output of UNSW's current annual expenditure on research. These affects are illustrated in Chart 4.1 which shows the approximate impact path of UNSW's 2014 research spending when it is sustained out to 2050. By 2050, this persistent increase of 9.7% in research and development spending per capita (relative to 2013 levels) will generate over $40 billion in additional GDP.

The model that underpins these results forecasts the effect of research spending on real GDP per capita using the elasticity, convergence and lag parameters describe above. These results are then multiplied by the forecast population size (obtained from the ABS) for each year to obtain the estimated effect on Australian GDP.

Chart 4.1 Impact of UNSW's 2014 and ongoing research spending on GDP



Source: Deloitte Access Economics

To measure the return on this stream of benefits and the associated investment costs it is necessary to convert this stream into present value terms. This is achieved by applying a social discount rate to the stream of benefits and costs. Harrison, (2010) notes that the Commonwealth's Office of Best Practice Regulation recommends a real discount rate of around 7%, justified as being approximately the before-tax rate of return on private investment in the economy.

Applying this discount rate, the total present value of economic returns from UNSW's 2014 research output are estimated to be around $106 and $190 billion in GDP over a period of 35 years. This is relative to the present value of the expenditure on research over this same period which is estimated to be almost $17 billion.[28] These estimates indicate a return to the economy on each dollar invested in university research of between $5 and $10.

These estimated effects are highly significant in magnitude, and may be viewed as an overstatement of the actual impacts on the economy from university expenditure on research. Nonetheless, the effect sizes are consistent with results from other studies both

[28] Investment made over time, but committed to today, need to be assessed in present value terms. Because of the trade-offs inherent in moving income (and consumption) across time, economic theory has established that $1 today is worth more than $1 tomorrow (and vice versa). So $1 invested each year over a period of 35 years is worth less, in present value terms, than $35 dollars. The modelling in this study considers a scenario where UNSW's estimated $1.04 billion of research spending in 2014 is sustained in real per-capita terms out to 2050 (therefore still growing with the population and rates of inflation over this period). In total, this spending out to 2050 is equivalent to around $48 billion (in 2014 dollars). In present value terms this is equivalent to a value of around $17 billion today (using a social discount rate of 7%). The returns (benefits) considered in this study are discounted in the same way (i.e. measured in present value terms).

in Australia and overseas and point to significant positive economic spillovers from university research expenditure.

Limitations

The estimated elasticity of university research to economic output applies to the average level of R&D expenditure per capita across the countries included in the growth model. To the extent that elasticity effects diminish as per capita spending on university R&D increases this elasticity may be an overestimate when applied to marginal estimates in Australia.

Expenditure on R&D represents a proxy for the stock of knowledge attributed to university research that exists in the economy. As such, marginal effects of ongoing expenditure on R&D may also represent the ongoing contributions of this stock of knowledge, and therefore overestimate the effects of marginal increases in R&D expenditure that occur in the short run.

The convergence term estimated by the model may represent a significant overestimate of the speed with which university research expenditure impacts economic output. This convergence term, in principal, relates to the speed with which other factors of production (such as capital) are accumulated in response to changes in the exogenous inputs of the model. This is used as a proxy for the time over which university research output matures to have an economic impact on the economy. As such, the estimated long-run economic contributions presented may take much longer to eventuate.

These figures are also estimates of the *contribution* of R&D expenditure at UNSW to economic output. It should be noted that they do not consider the counterfactual should UNSW not exist, which may involve some research funding being allocated to other Australian universities.

Nevertheless, these estimates of the long-term macroeconomic impact of university research output clearly demonstrate a strong relationship between university research and economic growth. However, they reveal little of the mechanisms by which the impacts occur, or the pre-conditions necessary to ensure that such benefits are realised. As such, these effect sizes cannot be reliably applied generally to individual research activities for the purposes of estimating economic impacts.

4.3.2.2 Faculty-level estimates of contributions

UNSW's Faculty of Engineering's total research budget was approximately $69 million in 2014.[29] A detailed assessment of these research projects revealed several active channels of knowledge flow with industry, and certain similar characteristics to industry engineering-related R&D. In light of these findings, Deloitte Access Economics identified conservative estimates of the return on investment from private sector engineering-related R&D, and applied these to the faculty's research expenditure in 2014.

[29] The estimated total value of 2014 Project Total Awarded Costs, provided by the Faculty. It should be noted that this is a measure of investment in research projects at the Faculty, which is different to the total expenditure on research at the faculty. It also includes costs attributable to research partners with the Faculty.

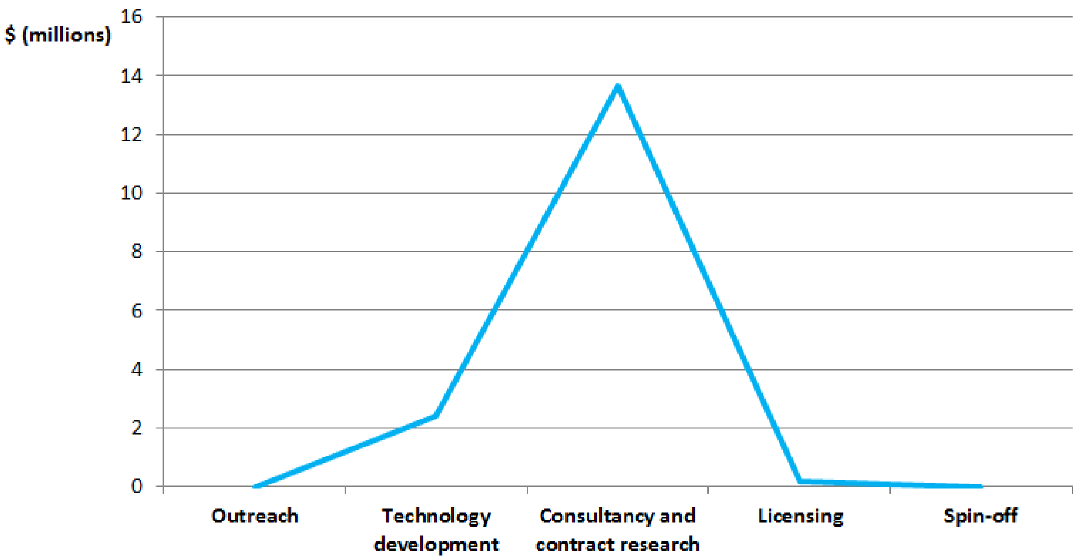
The *faculty investment approach* reveals how strategic research involving industry collaboration and other forms of knowledge exchange can yield significant economic contributions for UNSW.

In the future, developing a set of knowledge exchange metrics could provide UNSW with a deeper, more systematic understanding of where the economic (and social) impacts of research at the sub-university level is likely to flow through to external adoption and end-use. Where knowledge flow is most apparent, the economic and social impacts of research are more likely to emulate the impacts of applied private sector research, and the use of return on investment estimates for industry R&D may be appropriate to estimate these impacts.[30]

Research and industry collaboration

While the full spectrum of basic and applied research undertaken by universities can have positive impacts on the economy, research that is strategic and explicitly focused on achieving goals or impacts, is most likely to generate observable economic contributions. Much of the Faculty of Engineering's research in 2014 exhibited these characteristics (Figure 4.4).

Figure 4.4: UNSW Faculty of Engineering research revenue by category (2014)



Source: UNSW financial data

Figure 4.4 above shows how the vast majority of research revenue (84%) earned by the UNSW Faculty of Engineering in 2014 was from consultancy and contract research done on behalf or in collaboration with external bodies such as industry. Even technology development, the second largest source of revenue for the faculty (roughly 1% of total revenue), comes from ARC Linkage Projects which are done with partner organisations from

[30] Applying estimates from the literature on industry based R&D may in fact be a conservative approach, as many authors conclude that the impacts from more basic, 'blue-sky', research at universities likely exceeds that observed in industry.

the public and private sector. This highlights how a significant industry-based research activity is to the UNSW Faculty of Engineering.

Some examples of the applied nature of the Faculty's research which makes it highly similar to industry R&D include the following projects:

- UNSW engineering researchers are working with Bionic Vision Australia to develop **retinal implants** that can provide vision to patients suffering from degenerative retinal conditions. These implants and other applications in medical bionics created by this project will have immense commercial value
- Researchers are analysing environmental factors behind the **failure of rock bolts** used in mining to support rock walls, with the potential outcome of creating safer working conditions for miners and reducing the likelihood of mines shutting down because of bolt failure. This work is supported by industry partners such as Anglo Coal Australia, Beltana Highwall Mining, and Jennmar Australia.
- Researchers are working with Pacific Engineering Systems International to explore ways to tailor the properties of **composite propellers** to reduce underwater noise. This work can potentially have improvements in efficiency and fuel consumption, as well as improve naval defence capability and help the marine environment.
- Working with New Fluid Technology, researchers are aiming to develop a **rotor vane array wind power system** that can be used as a roof fence or balcony on existing or new buildings. The results of this research can potentially lead to the development of wind turbines that can better utilise the wind speeds of tall buildings, and contribute to energy security, carbon abatement, and sustainable living, and innovative architectural designs.
- Working with Onesteel Reinforcing, an Australian supplier of steel reinforcement products, researchers aim to better understand how to design and construct high-strength concrete columns with **high-strength steel reinforcement**. This research could help increase the competitiveness of Australia's manufacturing industry and enable the export of high-value-added technologies.

More generally speaking, there is strong evidence that UNSW's research agenda has a strong industry-based focus:

- UNSW is consistently the national leader in securing ARC Linkage funding. This scheme funds collaborate projects between university researchers and partner organisations in the public and private sector.
- For example, in 2013, UNSW received over **$13.2 million** in linkage grants for projects involving industry partners from the ARC – the second highest amount of funding for all Australian Universities.[31]
- Similarly, in 2014, UNSW won the highest amount of ARC Linkage Projects funding.[32] All in all, UNSW was successful in securing 30 linkage project grants totalling **$10.5 million** for industry-based collaborative research projects, with **$22 million** in cash or in-kind contributions from partner organisations.

[31] http://www.engineering.unsw.edu.au/energy-engineering/industry-partners

[32] https://research.unsw.edu.au/key-statistics-and-performance

Evidence of R&D returns from the literature

In light of the relatively high industry relevance of the UNSW Faculty of Engineering's research, Deloitte Access Economics surveyed a range of literature analysing the return on investment from private sector engineering-related R&D, to be applied to the faculty's research expenditure in 2014.

There is a wealth of literature on the private and public returns on R&D (see appendix). For example, in a recent *Econometrica* article, Bloom, Schankerman, and Van Reenen (2013) estimated a private rate of return to R&D of 21% and a social rate of return to R&D of 55%. The Productivity Commission has also produced a range of estimates. In one of their most statistically robust models, they found the spillover returns to domestic R&D averaging 50% (Productivity Commission, 2006). In other models, they found higher returns of between 85-180% in another paper, although the latter models had wide confidence intervals and high model sensitivity (Productivity Commission, 2008).

In a survey of the rates of return in the R&D literature, Dowrick (2003) surmised that the private return to firms is in the range of 20-30%; when spillovers are accounted for in microeconomic studies, these gross returns are in the range of 30-40%; and in macroeconomic studies which cover the entire economy estimates range from 50% to over 100%.

On balance, the social rate of return to UNSW Faculty of Engineering is estimated to be in the range of 25% to 40%, noting that this is likely to be a somewhat conservative estimate.

Applying industry-specific economic returns from the industry R&D literature to the totality of research at the UNSW Faculty of Engineering enables inferences to be drawn about the potential contributions of the Faculty's research, should this knowledge successfully flow through to industry end-use.

In 2014, the UNSW Faculty of Engineering's total contracted and proposed research funding was worth approximately $69 million. Given this, the present value gross social returns of its research activity would be approximately between $85-95 million.

Table 4.18: UNSW Faculty of Engineering funding and potential gross returns

Inputs/Outputs	Value
Total research funding	$69,122,677
Conservative scenario (25% gross social return)	$86,403,347
Optimistic scenario (40% gross social return)	$96,771,749

Source: Deloitte Access Economics (2015)

The conservative scenario in this instance may in fact be an underestimate. For instance, various estimates suggest that the social rates of return to publicly funded research are quite high in general. Scott et al (2001) found that recent literature on the returns of public research have ranged from 20-50% and higher. Other studies have adopted broadly similar ranges. Econtech (2006) observes that many studies place the economy-level social rate of return on public research in the order of 25-40% a year. KPMG Econtech (2010) concludes that most estimates of the rates of return on public R&D are between 20-40%, while Allen

Consulting Group (2011) finds that many studies place the social rate of return of public research in the order of 20-50%.

The applicability of rates of return from industry R&D literature to estimate the economic contributions of UNSW's research will depend on the extent to which the university's research exhibits similar characteristics to private research. The objectives of the research and the extent of industry collaboration can signal the extent of these similarities. A set of knowledge exchange metrics could provide UNSW with a better understanding of where its research and knowledge creation is most likely to flow through to external adoption and end-use, and therefore when industry rates of return (and which rates) are likely to be appropriate for economic contribution estimates.

In comparison to the results from the top down macro econometric approach, these estimated rates of return are much more modest. This likely reflects a number of complex factors, including but not limited to the following:

- The top-down analysis of the impact of university research captures the more long-term and diffuse effects of university research which are not effectively captured in more micro-economic studies at a firm or industry level.
- The estimates in the micro-econometric literature consider more applied examples of university research and do not capture the highly significant potential long-term effects generated by more pure and basic research.
- As previously stated, the top-down analysis of research spending impacts considers economic growth across countries and uses a highly indirect aggregate measure of research output – expenditure on research in universities. To the extent that the estimated effects in this model are in fact capturing the impacts of other correlated factors (e.g. prior research output) these effects may be overstated.

Overall, while the results from the top-down model demonstrate the significant relationship between research spending and economic growth, the results from this direct investment approach give a clearer and more direct sense of the returns that might be expected for individual research projects being undertaken within faculties such as the UNSW faculty of engineering.

4.3.2.3 Bottom-up estimates of contributions

UNSW researchers developed and patented an innovative membrane filter that removes pathogens and harmful molecules at low pressures, making water treatment more affordable. This technology has since become the industry standard in water filtration around the world, and in so doing has generated a range of direct, indirect and flow-on economic contributions.

With research into membrane technology beginning at UNSW in the 1970s and a breakthrough in 1978, the innovation initially began to realise an economic value in the early 1980s with its patent purchase by Baxter Travenol Laboratories and the creation of Memtec Limited. Following Memtec membrane's acquisition in 1998 by US Filter, the filtration technology has been iteratively improved and has significantly grown in terms of its impact on the domestic and international economy.

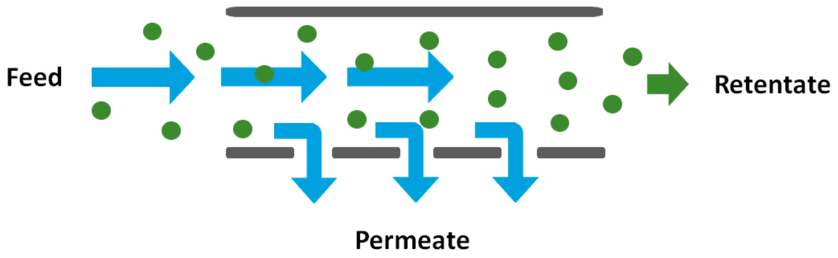
- **direct economic contributions**:

  - Significant government research funding streams resulted from the breakthrough in 1978. This ultimately helped establish the UNESCO Centre for Membrane Science and Technology, an internationally renowned institute
  - Significant returns on shares with Memtec Limited, with the shares held by UNSW increasing in value 25 times to $5 million in total in 1998
- **indirect economic contributions**:
  - The global market for microfiltration membranes was estimated to reach over a one and half billion dollars in 2013
  - Due to the rapid development and maturation of the technology, membrane filters have become increasingly cost competitive with rival technologies
  - HDR graduates trained in cutting-edge membrane technology research work in industry across the world
- **flow-on economic contributions**:
  - Memtec Limited was an Australian success story, which was bought in 1996 by US Filter for $600 million
  - A factory in Windsor, NSW still manufactures membrane filters based on Memtec technology. An approximate estimate of its value-add to the New South Wales regional economy is roughly $25 million
  - Environment and health benefits are two major positive externalities that arose from microfiltration technology

Membrane filtration

In membrane filtration, pressure is applied to a **feed** (such as wastewater), and a porous membrane separates the feed, allowing small particles such as water molecules to pass through the pores, while preventing larger particles such as dissolved and suspended solids and some microorganisms. The components of the feed which pass through the membrane is known as the "permeate" (or "filtrate"), while the component that does not is known as the "retentate" (or "concentrate").

Figure 4.5: Simplified membrane filtration diagram



Source: Deloitte Access Economics (2015)

In some instances, such as in the case of water purification, it is the permeate that is the desired output; in others, such as in the case of chemical concentration processes, it is the retentate that is the valuable end product; while in other situations, both the permeate and the retentate may be desirable.

Background

In the 1970s, researchers from the UNSW School of Chemical Engineering started investigating how to use membrane technologies to filter water and trap organic matter and pathogens, in order to produce clean drinking water.

The breakthrough in research came in 1978 with the creation of a hollow nylon fibre membrane. Unlike pre-existing filtration technologies, the membrane enabled water to be effectively filtered at low-pressures, without the use of many chemicals, and without large infrastructure or high energy costs.[33] Prior to this, scientists in the United States had already development high-pressure membrane filters for desalination, but this was a prohibitively costly technology. The membrane was patented by Unisearch Limited, the research commercialisation subsidiary of UNSW which evolved into UNSW Innovations.

The membrane patent was purchased in 1981 by Baxter Travenol Laboratories, which was manufacturing filters for Kidney Dialysis machines. This led to the further improvement of the technology and scaling-up of its production, before being taken to market. Baxter Travenol went into a joint venture arrangement with an associate of the University to develop and commercialise the membrane technology, spending over $1.5 million in the joint venture activity (Memtec Limited, 1984). In 1983, a completely separate company, Memtec Limited, was formed to take carriage of the membrane filters (Memtec Limited, 1984). Memtec Limited grew substantially in the United States and had subsidiaries in France, Italy, the United Kingdom and Germany. In 1998 Memtec was bought by US Filter for $600 million.

Direct contribution to UNSW

Membrane research at UNSW has led to a range of direct economic contributions for UNSW and its subsidiaries through external research funding, the establishment of research centres, and commercialisation revenue.

UNSW research costs & revenue

The initial costs of research leading up to the breakthrough in 1978 were relatively moderate. External funding was fairly small in the mid-1970s, in the order of a couple of thousand dollars. An Australian Research Council Discovery Grant in the late-1970s, which lasted three years, increased this external funding level to around $30,000 in total. Labour input into this research was also moderate, with the membrane research being conducted mainly by two academics and a university-paid research assistant (costing approximately $80,000 per annum in labour costs).[34]

Following 1978, membrane research activity at UNSW was able to secure increasingly significant amounts of funding. The UNSECO Centre for Membrane Science and Technology at the UNSW was originally established as a University Centre in 1987 and a

[33] Permeability parameters of a novel polyamide (MF) membrane. UNSW Nylon Membrane (Patent (1978), Michel Lefebvre, Chris Fell).
[34] From correspondence with Chris Fell.

Commonwealth Special Research Centre in 1988 which was funded through the Australia Research Council Special Research Centres program until the end of 1996.[35]

Likewise, with the establishment of the Cooperative Research Centres (CRC) Program in 1990 to support industry-led collaboration between researchers, industry, and the community; the CRC for Waste Management and Pollution Control was established with UNSW as the lead agent, and funding of $10.9 million were available from a period of 1997-2003 (Department of Industry and Science, 2015).

Commercialisation revenue

Membrane research at UNSW has also generated direct economic contributions for UNSW in the form of commercialisation revenue. When Memtec Limited was first established, the university took shares worth approximately $200,000 in 1983, which increased 25 times in value to $5 million in total in 1998, the benefits of which were split between Unisearch Limited, the membrane research academics, and the university faculty.

Indirect contribution to industry

Membrane research at UNSW has also led to indirect economic contributions for users of the technology, contributing to growth in the global microfiltration membrane market (total market size of $1.6 billion in 2013), decreasing the costs of filtration, and increasing the quality of water. Having been integrated into desalination plants, microfiltration technology has also contributed to increased water supply and drought-readiness in several parts of Australia.

Returns to users of UNSW research

Microfiltration technology used for liquid separation is a large and growing market. Microfiltration is used in a number of industries, including food and beverage processing, pharmaceuticals, portable water production, wastewater systems, industrial processes, and semiconductor fabrication. According to BCC Research (2013), the global market for microfiltration (MF) membranes was estimated to reach $1.6 billion USD in 2013 and is expected to grow to $2.6 billion USD in 2018 for a compound annual growth rate of 10%.[36]

The use of membrane filtration in water treatment has increased significantly since the technology was first commercialised in the 1980s. Due to the rapid development and maturation of the technology, capital costs and operation and maintenance costs of membrane filters have decreased significantly, making membrane filtration cost competitive with conventional processes. Membrane technology, for example, has been implemented in plants treating more than 100 million gallons per day, or 379 mega-litres per day (AWWA, 2006).

One of the reasons for the increasing use of membrane technology is the decline in its cost in recent years (AWWA, 2006). The costs of membrane system are dependent on a number of factors which differ for each user, such as market value of concrete and steel; local

[35] http://www.membrane.unsw.edu.au/about-us/centre-history/; http://www.membrane.unsw.edu.au/about-us/

[36] http://www.bccresearch.com/market-research/membrane-and-separation-technology/membrane-microfiltration-mst028e.html

construction costs; value of water lost in recovery; the cost of waste and discharge handling; and the specific filter design and configuration used (e.g. submerged microfiltration and ultrafiltration systems, and cartridge or pressure microfiltration and ultrafiltration systems). Along with technological advances, stringent water regulation and declining quality of existing water sources in many places have also increased demand on membrane filters.

In Australia, the membrane technology which was catalysed at UNSW also had an important function in desalination plants. For example, the Perth Seawater Desalination Plant and the Southern Seawater Desalination Plant in Western Australia provide almost half of Perth's water needs, and the Victorian and Sydney Desalination Plants are on standby to drought-proof the water supplies in the area. These plants use high pressure reverse osmosis technology, as well as membrane filters for water pre-treatment. For example, the Southern Seawater Desalination Plant, capable of producing around 100 gigalitres of water per year, uses membrane technology developed at the Evoqua Water Technologies factory in Windsor, New South Wales.

Returns to employers of HDR graduates

Further, the membrane research conducted at UNSW has also benefitted industry, with many HDR graduates trained in cutting-edge membrane technology research working in industry across the world. UNSW graduates have ended up in areas that use membrane technology both domestically and internationally, working for organisations such as Siemens Water Technologies and Sydney Water, as well as some of the largest membrane water treatment plants in places such as Singapore and California.

Flow-on contributions

Membrane research at UNSW has also led to flow-on economic contributions in the form of spin-off companies (with the membrane technology IP changing hands several times and a $600 million takeover in 1998), and spillover technologies (such as a gas backwash process that automatically cleans, and improves the effectiveness and longevity of membrane filters).

Spin-off companies

By 1987 Memtec's sales and revenue had grown significantly, and it employed around 70 people, including scientific and engineering staff, lawyers, accountants and IP professionals (Dwyer, 2003). At this point Memtec publicly listed on the Australian Stock Exchange in order to raise further capital to expand both in Australia and internationally. Memtec had also expanded overseas through business acquisitions, such as the acquisition of two filtration businesses in the United States in 1988, which gave Memtec additional IP portfolios and their extensive distribution and management networks. By 1995, Memtec had acquired a number of businesses and a portfolio of 654 patents. It had 298 trademarks around the world. Memtec was bought in a takeover by US Filter for $600 million in 1998.

Ultimately, it is highly difficult to attribute a dollar figure on Memtec Limited's overall value to the original research carried out by UNSW. On one hand, it can be argued that Memtec Limited would not have existed without the membrane research catalysed by UNSW in 1978. On the other hand, it can be argued that the physical and intellectual capital accumulated by Memtec Limited outside of UNSW is so significant that UNSW's contribution is relatively minor in comparison. All in all, the value of UNSW's contribution to Memtec Limited can be anything from the initial patent sale from Unisearch to the final $600 million buy-out by US Filter.

The technology has since traded hands several times. It was later sold to Vivendi (that later became Veolia), a French water and waste management company, before being sold onto Siemens Water Technologies. In 2014, the Siemens Water Technologies business was officially ended after being acquired by a private equity firm and renamed Evoqua Water Technologies.[37] The membrane product line is currently sold under Evoqua and has thousands of microfiltration and ultrafiltration installations around the world for municipal and industrial applications.[38]

However, despite leaving Australian hands, the production of hollow fibre membranes continues to benefit New South Wales due to the existence of an Evoqua Water Technologies factory in Windsor, New South Wales that manufactures polymeric tubular membranes based on Memtec technology for the global market. This site, about 50km north-west of Sydney, is the former headquarters of Memtec Limited.[39] As of 2008, when it was operated by Siemens Water Technologies, it employed 250 people in its manufacturing and in-house research, development and engineering facilities.[40]

Assuming that all of these were full-time workers employed in professional, scientific and technical services, and that the number of employees has not changed significantly since 2008, then an approximate figure for the economic contribution of this factory on the New South Wales regional economy is **$25 million in GSP value-added**.

Spillover innovations

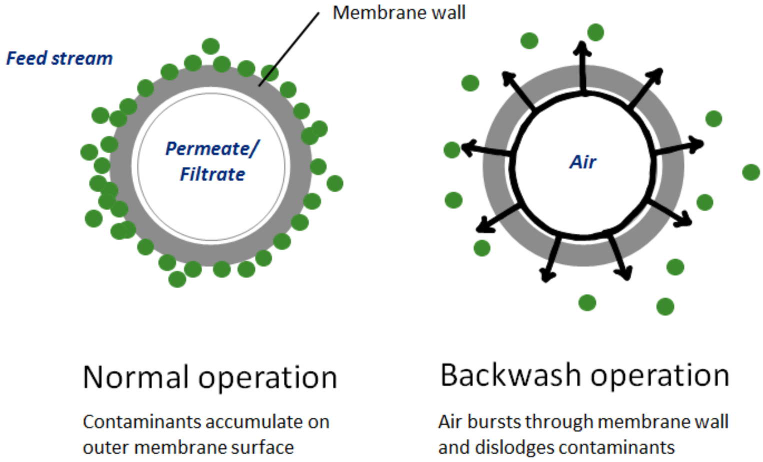
Perhaps the most notable spillover innovation associated with the membrane filters was the independent development of a gas backwash process, which cleans the membranes of accumulated impurities, and improves membrane effectiveness and longevity.

One of the major reasons for a loss of membrane performance overtime is **membrane fouling -** where substances coat the membrane surface. One way to prevent fouling is through the use of a backwashing system such as a gas or liquid backwash.

A key component in the success of Memtec membrane filtration was the incorporation of a **gas backwash**, which was developed independent of the membrane research done at UNSW. This innovative gas backwash technology – known as Continuous Microfiltration (CMF) - prevented membrane fouling and allowed for effective continuous performance of the membrane filters.

[37] http://www.waterworld.com/articles/2014/01/siemens-changes-name-to-evoqua.html
[38] http://www.evoqua.com/en/brands/Memcor/Pages/default.aspx
[39] http://www.smh.com.au/news/water-issues/getting-a-taste-for-recycled-ideas/2008/02/15/1202760599549.html?page=3
[40] http://www.siemens.com/innovation/en/publikationen/publications_pof/pof_fall_2008/rohstoffe/wasser.htm

Figure 4.6: Gas backwash technology



Source: Adapted from MacCormick, "The Application of Microfiltration in Water and Wastewater Treatment", in *Modern Techniques in Water and Wastewater Treatment* (1995)

Another innovation increasing the efficiency of membrane filters was the move away from flat to tubular membrane arrangements. In commercial applications, membrane filters typically have to be packed into tight spaces, while maintaining the level of filtration required. The independent development of tubular, fibre based membranes enabled more filtration area per cartridge, and brought down the costs of membrane filtration.

These and other spillover innovations have improved membrane filtration technology generally, yielding economic gains for various industries and users worldwide.

Broader society

In addition to the economic contributions associated with the membrane filter technology initially developed by NSW, there are clear environmental and health benefits, particularly with respect to water filtration.

Membrane filtering technology is largely chemical-free. Microfiltration is able to filter particulates and microorganisms without the use of conventional chemical coagulants. There are also low energy requirements, lower chlorine requirements for disinfection, and they have a much smaller footprint in terms of land use. Further, microfiltration is able to effectively purify industrial wastewater, removing heavy metals and other harmful pollutants from the water supply, and reducing overall reliance on often scarce freshwater sources. In totality, these features of membrane filtering result in significant environmental benefits.

With regards to health benefits, microfiltration is exceptional at filtering out harmful microorganisms from the water supply. Cryptosporidium is a high durable protozoan parasite that is commonly found in surface water and causes gastrointestinal illnesses in humans, and can even survive common disinfectants such as chlorine-based disinfectants. However, microfiltration technology such as Memtec is capable of reducing the presence of their microbial cysts significantly.

There were a number of waterborne outbreaks in the United States in the mid-1990s. According to Corso et al. (2003) in an assessment of the 1993 cryptosporidiosis outbreak in Milwaukee, the average cost for persons with mild, moderate, and severe illnesses were $116, $475, and $7,808 respectively. The Safe Drinking Water Act – the main federal law which ensures the quality of drinking water in the country – was amended to regulate the maximum level of containments that were allowed in drinking water. The Interim Enhanced Surface Water Treatment Rule, finalised in 1998, stipulated a 2-log reduction of Cryptosporidium for public water systems serving 10,000 or more people that use surface water or groundwater sources close to surface sources.[41]

Although existing filtration technology (e.g. sand filtration) could not achieve this level of purity, membrane technology could. This meant there was a huge market opportunity for Memtec, since the only other option for achieving this level of water purity was UB light treatment, which was not sufficiently developed enough in the late 1990s to be an economic alternative. The new regulatory environment in the US was one of the reasons why Memtec Limited was bought for $600 million by US Filter in 1998.

Finally, it should be noted that membrane technology can play an important role in developing countries and in humanitarian efforts. For example, the Skyjuice Foundation, a not-for-profit organisation based in Sydney that was launched by a former Memtec employee, develops membrane water filtration units that can produce safe potable water without power or chemicals. These have been used in communities around the world with limited access to clean water, and in humanitarian and emergency relief situations.

The economic contributions of Silicon Photovoltaic Solar Cells

UNSW set up the first school in the world dedicated to university degree programs in photovoltaic research and education, and UNSW researchers have been responsible for significant increases in the efficiency of commercial photovoltaic (PV) solar cells made from common silicon semiconductor material. These training and research breakthroughs are helping make solar technology a viable competitor in the global energy market.

PV research at UNSW began in the mid-1970s. With a number of research breakthroughs in cell efficiency since the 1980s till the present day, the economic value of this research activity has grown significantly and matured over the last few decades. In particular, in early 1990s, former UNSW HDR graduates in PV technology founded and co-founded a number of internationally successful PV manufacturers in China.

- **direct economic contributions**:
  - The research into photovoltaics catalysed by UNSW's achievements in this area have resulted in significant streams of funding, both from government and the PV industry, notably by bringing investments in from overseas industry partners
  - A number of Chinese spin-off companies (as well as a number of small Australian companies working in engineering consultancy, research services,

[41] The log-reduction terminology is used by water treatment engineers to express levels of decreased biological contamination as a result of disinfection/cleaning/treatment processes. E.g. a 1 log reduction means the number of biological contaminates is 10 times smaller (90% of microorganisms removed by process); while a 2 log reduction means it is 100 times smaller (99% removed).

and commercialisation of PV innovations) have been started by UNSW HDR graduates

- **indirect economic contributions**:
  - UNSW PV research caused a direct movement in manufacturing of solar panels to China, lowering production costs
  - Post-graduates with research experience in PV at UNSW are widely sought after by industry
- **flow-on economic contributions**:
  - Spin-off companies such as Suntech Power, and BT Imaging in Sydney
  - Solar energy will play a significant role in energy security, carbon abatement and potentially bring increased competition to the energy market

Photovoltaics

The term photovoltaics refers to a group of methods which involves the direct conversion of light into electricity. This is accomplished using solar panels which are comprised of a number of small units known as photovoltaics cells, commonly made from semiconductor materials such as silicon.

Although the phenomenon of electricity generation from light exposure has been observed and experimented with since the 1800s, it was not until the 20th century that the science and technology was sufficiently understood to create the first practical photovoltaic panels. In its most typical design, atoms are added to the semiconductor to increase its conductivity. By doing this, it is possible to create an interface known as a p-n junction between two types of semiconducting materials. Light which falls into the photovoltaic cell excites negative and positive charge carriers in the semiconducting material. This can be used to generate electricity needed for practical applications. Based on this concept, the first silicon solar cell was developed by Bell Labs, with an efficiency of up to 6%, in 1954.

Background

The origin of PV research at UNSW began when the UNSW photovoltaics group was initiated by Professor Martin Green after he was appointed there as an academic in 1974 (Green, 2015). Within a short space of time the PV research group at the university had become one of the most respected internationally.

By 1983, this group of researchers had achieved the world's first 18% efficiency silicon cell. After some design changes to the cell, the efficiency was increased to be above 19%. Two years later, in 1985, the team produced the world's first 20% efficient cell. Following this, the work was split into two different strands – one which pursued even higher efficiency solar cells of 25% efficiency, and the other, which explored ways that the 20% efficiency silicon cell could be fabricated at low cost (Green, 2015).

The first goal was achieved in 2008. In 1999, progressive refinements to their solar cell designs had increased efficiency to 24.7%, and a revision of the international standard by which solar cells are measured led to the efficiency being remeasured as 25% (Green, 2015).

The second goal is ongoing. Martin and his team focused on materials that were cheap and scalable. This was principally silicon, which is also an ideal material for solar cells - it is non-toxic, and the second most abundant element in the Earth's crust (Green, 2001).

While silicon solar cells have a lower efficiency than what other materials in the lab can achieve, these materials are often in short supply and not scalable for industry. In this respect, UNSW's PV research was highly strategic with regards to its expected economic impact. As part of their research activity, they have also engaged in a number of industry partnerships to advance the commercialisation of their technological innovations.

One of UNSW's key industry partnerships is with solar-energy giant Suntech Power, based in China. Suntech was founded by UNSW alumnus Dr Zhengrong Shi and through unique collaboration, UNSW students and staff are involved in the complete technology-development process. The strategic focus for PV researchers with China was in part because of the fact that the Chinese PV industry was willing to make massive investments in the PV solar supply chain, the high degree of confidence and enthusiasm that industry and government there had for solar as an alternative energy source, and the massive manufacturing efficiencies that exist.

Direct contribution to UNSW

The success of PV research at UNSW has led to a range of direct economic contributions for UNSW in the form of significant government funding and funding from external industry sources. HDR students with PV experience from UNSW are also in high demand by industry around the world.

UNSW revenue

UNSW PV research has been recognised internationally as being among the best in their field. Due to this global reputation and the applied nature of their work, their research activity has received strong funding backing.

For example, in 1983, the US Department of Energy (DOE) funded Professor Martin Green's work directly, making it the only research group outside the US to be financed by the DOE. When this funding source ended in the 1980s, the PV research group was given by an Australian federal government Special Research Centre grant in 1990. This was replaced by the Australian Research Council's Centres of Excellence program which helped finance the ARC Photovoltaic Centre of Excellence in 2003.[42] For example, from the beginning of 1991 to the end of 1999, a total of approximately $8.8 million in research funding was awarded to Professor Green's research into photovoltaics devices through the Australian Research Council/Special Research Centres.

ARC funding was initially scheduled to continue until the end of 2007, but upon review in 2005 and 2006, this funding was extended until 31st December 2010. Due to the growth of the photovoltaics industry, and the strength of UNSW's research contribution to this area, the Centre is now dependent upon industry-related funding for research for near-term outcomes and upon more academically-orientated ARC, the Australian Renewable Energy Agency (ARENA) and international schemes for its long-term research while remaining

[42] https://www.themonthly.com.au/eric-knight-shi-zhengrong-sun-king-eric-knight-3363

under the ARC Centres of Excellence umbrella beyond 2010. In fact, total research funding for the Centre from industry and other funding sources reached record levels in 2014 (ARC Photovoltaics Centre of Excellence, 2014). For example, ARENA funding for solar R&D projects announced in August 2014 secured nearly $7 million in funding for three UNSW research projects.[43]

Likewise, industry backing from Suntech Power and other PV firms has been significant. In fact, interest from industry has grown despite the Global Financial Crisis in 2008, partly due to UNSW's leadership in the field as well as a perception that solar energy will become increasingly important in the near future. For example, despite financial difficulties, Suntech Power has $6 million committed to projects with UNSW until 2018.[44] Another key industry partnership was with Sunrise Global Solar Energy in Taiwan. UNSW offered special intellectual property (IP) rights to the company, allowing Sunrise to use the IP for free in exchange for access to company's production facilities, which allowed UNSW to tailor its technologies to suit commercial equipment and a commercial environment.

HDR student returns

Over the course of the early 1990s, a large number of Chinese post-graduate students studied with Martin and his team and brought back a significant amount of technical expertise back to China. A number of spin-off companies were started by Chinese UNSW post-graduate students. The most notable among these was Suntech Power, founded by UNSW alumnus Dr Zhengrong Shi. Further training and support from UNSW helped these companies grow and ensured technological industry transfer of knowledge. Other manufacturing companies subsequently founded or co-founded in China by former UNSW researchers include JA Solar and Sunergy.

Due to the reputation of UNSW in PV technology, post-graduates with research experience in PV at UNSW are widely sought after by industry. Having a UNSW education became the industry standard when establishing and operating a solar panel plant in China, and a number of CEOs and chief technology officers in Chinese PV firms have UNSW credentials.[45] Of the top five PV manufacturers globally in 2014, all have had former UNSW researchers as CTOs or founders, or have had them at important stages of their development, such as in their initial public offering.

Indirect contribution to industry

PV research activities at UNSW has helped lower production costs, and create solar cells that are constructed from affordable materials and have higher levels of energy efficiency. Their research will only increase in economic importance as the global solar energy market grows in the coming years.

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[43] http://arena.gov.au/programmes/research-and-development-programme/round-1/;

[44] http://www.smh.com.au/environment/climate-change/solar-giant-to-close-australian-rd-unit-20140822-10758l.html; https://newsroom.unsw.edu.au/news/science-technology/solar-savings

[45] http://www.engineering.unsw.edu.au/emag/featured-story/solar-genius-celebrates-40-years-unsw

Returns to users of UNSW research

PV research undoubtedly created significant financial benefits. Due to their work with Chinese manufacturers, UNSW PV research helped trigger a major shift in the manufacturing of solar panels to China which significantly lowered production costs.

Products that use cheap, standard semiconductor materials such as silicon which have higher efficiency also generate greater levels of consumer demand. Variants of their 25% efficient PERL cell, known as Pluto, have been commercialised by Suntech Power.[46] Developed by Suntech's R&D team in collaboration with UNSW, the Pluto cell achieved a world record of 20.3% efficiency for a production cell using standard commercial-grade p-type silicon wafers.

Likewise, manufacturing capacity based on UNSW's PERC technologies has been **growing from close to $1 billion dollars per year in 2011**. According to the International Technology Roadmap for Photovoltaic (ITRPV, 2015), this cell technology is expected dominate the future crystalline silicon PV market by 2020.

Further, the overall global solar energy market is expanding, meaning that technological innovations developed by PV researchers at UNSW are likely to grow in terms of their economic importance in the near future. Global installed capacity of solar PV reached 136 GW in 2013, almost all of it built in the last decade and over 70% in the last three years (World Energy Outlook, 2014), and the solar photovoltaics market (including modules, system components, and installation) grew to $91.3 billion from $79.7 billion in 2012 (Clean Edge, 2014). Clean Energy Trends (Clean Edge, 2014) projects that the cost of solar energy will continue to drop an estimated 7% per year over the next decade, to $1.21 per watt by 2023.

Flow-on contributions

PV research at UNSW has generated major spin-off companies, including the former market leader in PV manufacturing, Suntech Power. More broadly speaking, cutting-edge PV innovations conducted by research institutions such as UNSW are crucial in addressing the important economic and policy issues of energy security and carbon abatement, as well as increasing competition in the energy market for consumers.

Spin-off companies

The most well-known example of a spin-off company is Suntech Power, founded by a UNSW post-graduate student. Before its default, it was a major global solar panel producer. In 2005 the Suntech Power Holdings Company became the first privately owned company based in China to list on the New York Stock Exchange, and by 2010, Suntech's market valuation was approximately US$6 billion, making it the second-largest solar manufacturing company in the world.[47]

Partly as a result of a contraction in demand and a resulting overcapacity in solar panel production in recent years, Suntech has recently experienced financial difficulties and has recently gone into administration and been financially restructured. Under new owners,

[47] https://www.themonthly.com.au/eric-knight-shi-zhengrong-sun-king-eric-knight-3363

Suntech has maintained production, producing 2GW/annum of modules and continues to support research at UNSW. Other spin-offs founded or co-founded by former UNSW researchers, such as JA Solar and Sunergy, have performed well in the marketplace.

In terms of domestic spin-off companies, BT Imaging is a Sydney, Australia based supplier of R&D and process inspection tools to the photovoltaic manufacturing industry. BT Imaging was a spin-off company from the School of Photovoltaic and Renewable Energy Engineering at the UNSW. Since 2008, the company has designed, developed and released a number of products that are crucial to the photovoltaic manufacturing industry. BT Imaging is a leading supplier of photo luminescence imaging technology and equipment which is used throughout the whole PV supply chain, from silicon blocks to wafer, cell and modules to inspect defects in the silicon material, and to diagnose solar cell process issues. This technology will become more important than ever as solar cell manufacturing expands.

Broader society

Solar power, along with other renewable energy sources, is expected to have a significant impact in the coming decades that is difficult to measure. This is due to the role it could have to play in terms of energy security and carbon abatement. The impact that UNSW research could play in this is difficult to measure in economic terms at this stage, but could be substantial.

First, the role it could potentially play in a secure energy source should not be understated. Following the 1973 oil crisis, interest in alternative energy sources other than fossil fuels such as solar power increased. This also occurred after the Chernobyl incident in 1986 that put the safety of nuclear power plants into question (Haberlin, 2012). More recently, the Fukushima Daiichi nuclear disaster in 2011 has also spurred interest in alternative energy sources (Clean Edge, 2014). This is on top of growing energy requirements due to a growing world population and rising living standards.

Solar power could also play a significant role in carbon abatement. Currently, the Grattan Institute (2015) estimates that electricity generated from solar PV will reduce emissions by an estimated 66 million tonnes of carbon dioxide by 2030, or about four million tonnes a year. While they note that this is less than 10% of the abatement required to achieve Australia's 2020 emissions target over the next five years, they note that advancements in battery storage will make solar power a desirable and cost-effective choice for many households in Australia, even without the need for subsidies. This could potentially enhance the carbon abatement potential of solar power, and reduce the cost of doing so as well.

Finally, UNSW's research and development in PV technology can potentially bring benefits to residential and commercial consumers. Continual improvements in commercial PV designs, along with competitive pricing of solar energy, can increase competition in the energy markets. With competitive pricing, this increase in competition can benefit consumers by expanding consumer choice over energy sources as well as introducing downward pressure on the cost of energy.

The economic contributions of Kakadu software

Research conducted at UNSW has resulted in a software development kit for image, known as Kakadu software, which is used by more than 300 companies worldwide, including Sony, HBO and Disney. This software package is part of a larger research program that is changing the way industry approaches cinema and digital content.

The initial software toolkit was developed in 2000-2001, and since then it has been has been significantly re-developed, with multiple products and functionalities added. With the growing market importance of the JPEG 2000 image compression standard that Kakadu software is designed to create applications for, it is likely that the full economic value of Kakadu software has yet to be fully realised.

- **direct economic contributions**:
  - Kakadu software has generated **tens of millions** in benefits to both UNSW and users of its technology over the past ten years
  - As the image standard that Kakadu was created to encode and decode grows in terms of industry usage, the market for Kakadu software is likely to grow as well
- **indirect economic contributions**:
  - The market for Kakadu is very high value and the main benefits for users are in reduced communication time and memory space used for storage and computation
  - Applications include image archiving and databases, medical imaging, satellite imagery, digital cinema, and scientific and industrial research
- **flow-on economic contributions**:
  - Most of the intangible benefits come in the form of Kakadu being a vehicle for future innovations and adoption of the industry standard. One of the key motivations behind the licensing of Kakadu is to promote the JPEG 2000 format more generally

Image compression

JPEG 2000 is an image compression standard and coding system, and is the successor to the well-known traditional JPEG format that is widely used for the compression of digital images. The goal of image compression is to reduce the redundancy in the image data in order to store or transmit the image data in a more efficient format.

Figure 4.7: Bad image compression (top) compared with good image compression (bottom)

Source: Deloitte Access Economics (2015)

Both the JPEG and JPEG 2000 standards (as well as many others) were created by the Joint Photographic Experts Group committee, a joint working group of the International Standardization Organization (ISO) and the International Electrotechnical Commission (IEC) that discusses and creates the standards for still image compression and processing.[48]

Background

Kakadu Software is a software development kit (SDK) – a programming package that enables programmers to develop applications for specific purposes – for encoding and decoding JPEG 2000 images.

Kakadu software was developed by Professor David Taubman of the UNSW School of Electrical Engineering and Telecommunications. This occurred during 2000-2001 while writing a text book on image compression software. At the time Professor Taubman could not motivate the discussion on image compression software in his book with the prevailing compression code because of licensing restrictions, he developed a new code which became the original Kakadu software toolkit, named after Kakadu National Park in the Northern Territory. While Professor Taubman’s contribution to developing JPEG 2000 began prior to him joining UNSW, the research for Kakadu software was undertaken at UNSW and can be attributed in part to UNSW as a research institution.

[48] http://www.jpeg.org/about.html

Following its genesis, Kakadu software was commercialised by the university through UNSW Innovations. The software has been continually improved and redeveloped upon over the years, with multiple products and functionalities added, which has helped greatly expand its utility and consumer base. UNSW Innovations has sold over 450 commercial licenses over the last 10 years or more. There are currently around 170 active licenses. The users of these licenses include a number of major companies, such as Sony, HBO, and Disney, as well as a number of niche companies.

Kakadu software as a commercial toolkit has a variety of applications, and was licensed with this purpose in mind. A university library license is available which is related to the book and there is a continuing academic purpose to the software with a large number of free license users who work in research in development across the world.

Direct contribution to UNSW

The commercialisation of Kakadu software by UNSW Innovations has yielded extremely high returns relative to its initial research cost. Moreover, the market for Kakadu is growing as industry demand for its functions grows.

UNSW research costs & revenue

The original resource cost of developing Kakadu software is minor and much of the gains to the university come primarily through the licensing and commercialisation activity regarding the software toolkit. Nevertheless, it has also generated a direct research benefit. Because of Kakadu, Professor Taubman has been able to exploit economies of scope in other research activities.

Research subsidiary costs & revenue

Through UNSW Innovations, Kakadu software is sold under a number of licenses that can serve the needs of a variety of users:

- The eval pack is a six month licence to consumers that wish to explore the potential of the SDK and so are usually converted into a commercial licence.
- The commercial licences are bought by companies who can generate a commercial return – these vary from a small outfit of two or three people to large corporations. These licenses are the core of the commercialisation business.
- The pub serv licences are primarily to universities and libraries that will not derive any commercial benefit, but gain internal efficiency from the applications that they create.
- The single licence is a perpetual licence to a named individual who wish to use the software, these are often students or academics and they only pay once to receive all future updates etc.
- The speed pack is an incremental product sold to holders of the commercial SDK, rather than new users, for those prepared to pay an additional price for additional speed performance.

Further, the market for Kakadu is continuing to grow and Kakadu software is continually being upgraded – for example, the next version of Kakadu will include a patent for improving compression performance. An essential factor in all this is that as JEPG 2000 becomes increasingly used in various applications, Kakadu has high potential to be increasingly demanded for application development.

Drawing on financial information, since it was first developed and commercialised in the early 2000s, Kakadu software has generated **tens of millions** to UNSW and users of the software over the past ten years. Moreover, the ongoing expenses of administering the program are relatively small compared to this.

For a program that was initially developed within six weeks within an almost pure research context, these are significant returns that could not have been anticipated from the outset given the incidental research costs.

Indirect contribution to industry

The research into Kakadu software conducted at UNSW has resulted in a product that has very high value for its users, and as a result it is likely to have made a significant economic contribution to end users across a vast array of industries.

Returns to users of UNSW research

The market for Kakadu is very high value and the main benefits for users are in reduced communication time and memory space used for storage and computation. While, the software development kit itself does not create a direct economic impact for industries, it is an essential tool used to implement applications that create impact. In that sense, Kakadu is only part of the IP that creates the end value.

Kakadu software is used by more than 300 companies worldwide, including Sony, HBO and Disney. Most of the companies who use the license are in the entertainment space since JPEG 2000 is a highly useful format for cinema, broadcasting, and backend editing and transformation. In digital cinema and the broader media industry, for example, there has been a push towards techniques such as high-dynamic range (HDR) imaging, which is able to better match the capacity of the human eye. Distributors and content creators wishing to satisfy these growing deliverable requirements require image compression standards and coding systems such as JPEG 2000 which can support a greater number of bits per pixel. These changes in the industry are a potential area of opportunity for Kakadu.

The medical imaging space is also an area of opportunity for Kakadu. JPEG 2000 can be used to encode files completely or partially without loss (i.e., it allows for original data to be perfectly reconstructed from compressed data) and provides good overall compression performance, making it useful in medical imaging which relies on undistorted images for accurate diagnoses. Likewise, because of its high quality image properties, geo-spatial mapping and satellite imaging are also areas of significant opportunity, with military organisations being among the users of Kakadu.

Flow-on contributions

Kakadu software was one of the pioneering technologies in JPEG 2000 implementation and has high potential to remain a significant contributor to this area into the future. Because of the growing importance of JPEG 2000, Kakadu software's contribution to the economy is likely to be much broader than just the revenue earned from licensing.

Broader society

Most of the intangibles benefits come in the form of Kakadu being a vehicle for future innovations and adoption of the industry standard. One of the key motivations behind licensing and promoting Kakadu is to promote the JPEG 2000 format more generally.

JPEG 2000 is an image standard that has yet to be fully adopted. However, it has a number of technical specifications that make it useful for a number of applications. Applications designed using Kakadu can take advantage of many of the features of JPEG 2000. These applications include:

- **Image archiving and databases** - JPEG 2000 files typically can have extensive metadata stored with them, making it useful in archiving films and images and in creating databases
- **Medical imaging** - JPEG 2000 can be used to encode files completely (or partially) without loss, and provides good compression performance, making it useful in medical imaging which relies on undistorted images for accurate diagnoses
- **Cultural heritage preservation** - The high quality of JPEG 2000 images makes it a useful standard in cultural heritage preservation, where images need to be as accurate as possible
- **Digital cinema** – JEPG 2000 features such as simple editing access, lossless compression capabilities, metadata insertion, and scalability in resolution and quality make it useful for the demanding deliverable requirements of digital cinema
- **Remote sensing and geographic information systems (GIS)** – numerous capabilities and functionalities of JPEG 2000 makes it an ideal technology for remote sensing and GIS applications
- **Digital photography** – JPEG 2000 can allow for efficient, high quality compression; rapid decoding of images for camera display screens; and metadata for the proper use and display of digital images
- **Scientific and industrial research** - JPEG 2000 offers many useful features for management of information in scientific and industrial research such as proper colour management and extensive options to add user defined and standard metadata to an image file

The fact that Kakadu software has the potential to be used in a number of areas, from entertainment to medical diagnosis and cultural preservation, means that it could have numerous flow-on contributions for broader society which are varied and difficult to measure. What is clear, however, is that Kakadu is likely to become a highly valuable tool as the economy experiences greater levels digitalisation and the number of JPEG 2000 users in the economy increases.

As such, Kakadu is not just being exploited for commercial purposes. For example, there are over 1000 non-commercial licenses issued for free to research groups to further research into image compression, and the JPEG 2000 architecture in particular.

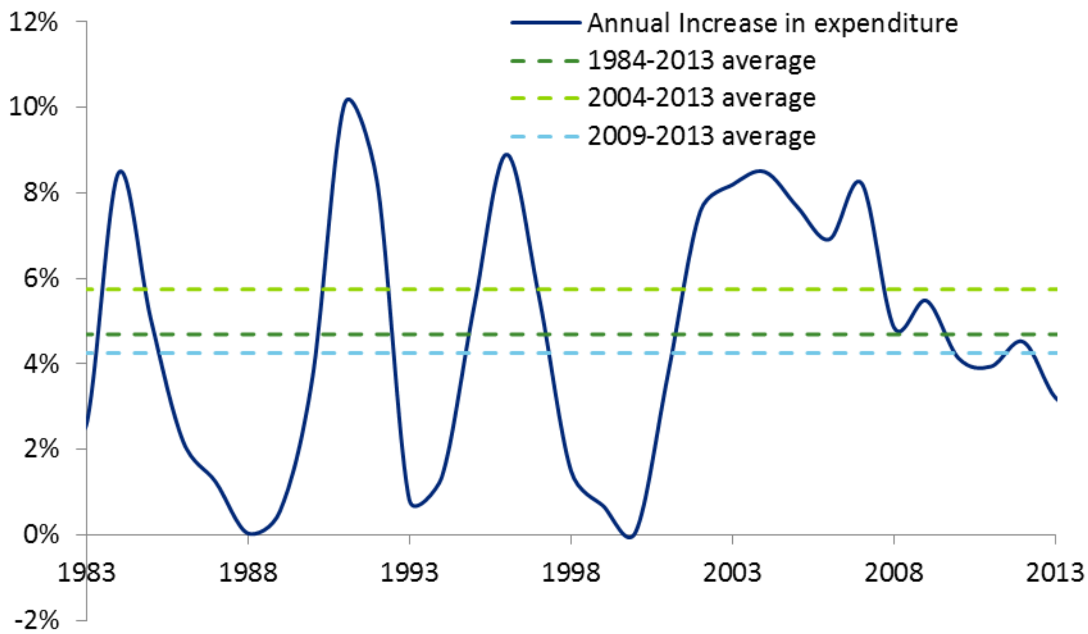
5 Research universities supporting economic growth

University research activity impacts economic growth through its effect on productivity. Indeed, looking forward Australia's research universities will play a critical role in supporting economic growth and wellbeing.

5.1 How investments in university research affect economic growth

Based on data from the ABS and the OECD, university research expenditure per capita in Australia is estimated to have grown by 4.7% per year on average from 1984 to 2013. More recently, this rate of growth has moderated slightly, with average annual growth from 2009-2013 estimated to be 4.3%, as demonstrated in Chart 5.1

Chart 5.1 Real growth in university research expenditure per capita, 1983-2013[49]



Source: OECD, Deloitte Access Economics

Utilising the modelling undertaken for this study, it is possible to estimate the consequences different scenarios of research expenditure growth could have on the economy.

[49] This data series was estimated using a cubic-spline interpolation of data from the OECD. Values in this dataset are measured in constant 2010 US PPP dollars. See Appendix A for further detail on the data underlying this model.

This analysis considers three different scenarios to illustrate this impact, relative to a base case scenario where there is no real increase in per capita research spending in 2014.

1. A trend growth scenario where research spending is assumed to grow by 4.3% in 2014, following the 5-year average from 2009-2013.
2. A below trend growth scenario where research spending is assumed to grow by 2.1% in 2014, half of the 5-year average from 2009-2013.
3. An above trend growth scenario where research spending is assumed to grow by 5.7% in 2014, following the 10-year average from 2004-2013.

In each scenario the estimated effect relates only to the level increase in research expenditure in 2014 that is sustained out to 2050. That is, the modelling only includes the impact of an increase in 2014 which is sustained in levels turns out to 2050. It does not include the impact of any further increases (at trend or otherwise) which may occur from 2015 onwards.

It should also be noted that this model allows for population growth over the period 2014 to 2050, using projections from the ABS (Cat No. 3222, 2012). This means that while the effect of research expenditure on income per head is a function only of the estimated effect elasticity, lag-period and convergence parameter the estimated *total* impact also includes the contribution made by population growth over the period. Nonetheless, this factor effects both the total expenditure and estimated impact figures equally, so the estimate return on investment from expenditure on GDP is invariant to population growth.

The results from these scenarios are outlined in Table 5.1. These results include the total present value of the additional expenditure associated with each growth scenario – and the estimated impacts – relative to the base case where there is no growth in expenditure.

Table 5.1: Estimated impacts on GDP ($millions)

Scenario	Total expenditure (present value)	Estimated impact (present value)	
		Lower bound	Upper bound
1	$7,475	$46,719	$83,570
2	$3,738	$23,360	$41,785
3	$10,092	$63,073	$112,823

Source: Deloitte Access Economics

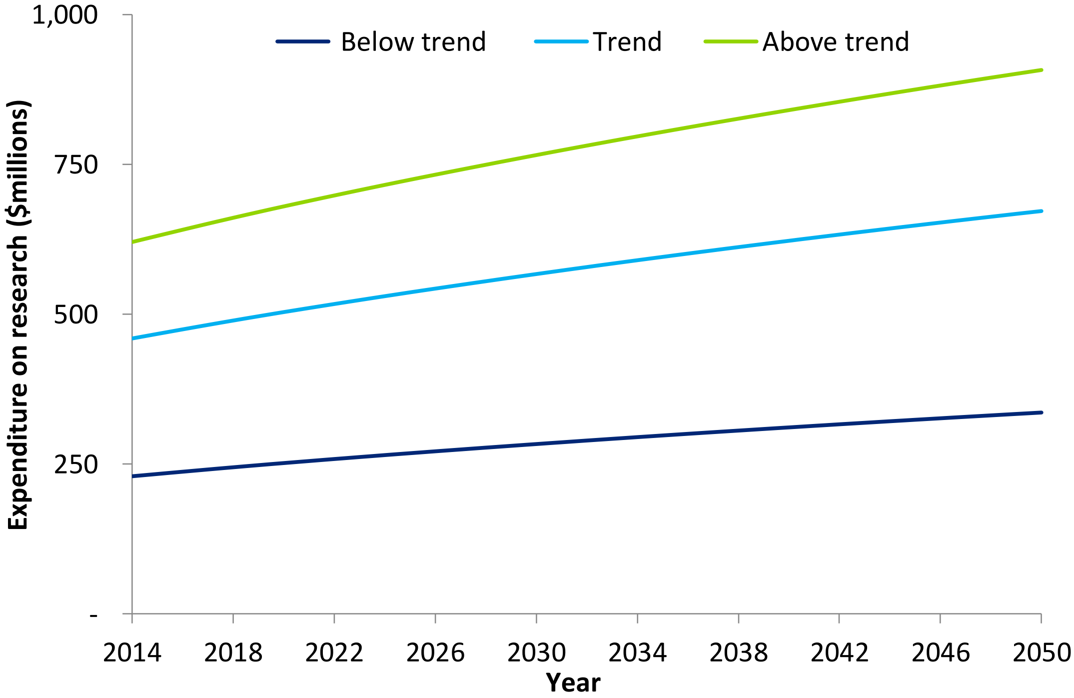
The results demonstrate that, following the current 5-year trend scenario, a permanent 4.3% increase in real per capita spending on university research (equivalent to $460 million in 2014, or a PV cost of around $7.5 billion out to 2050) would create an additional $47-$84 billion in Australian GDP in present value terms out to 2050.

Compared to this trend scenario, if growth in real per capita spending on total university research:

- was halved in 2014 (to 2.1%), and this level of research expenditure was sustained out to 2050, GDP would be $23-$42 billion lower (in present value terms)
- was raised to 5.7% in 2014, and this level of research expenditure was sustained out to 2050, GDP would be $16-$29 billion higher (in present value terms)

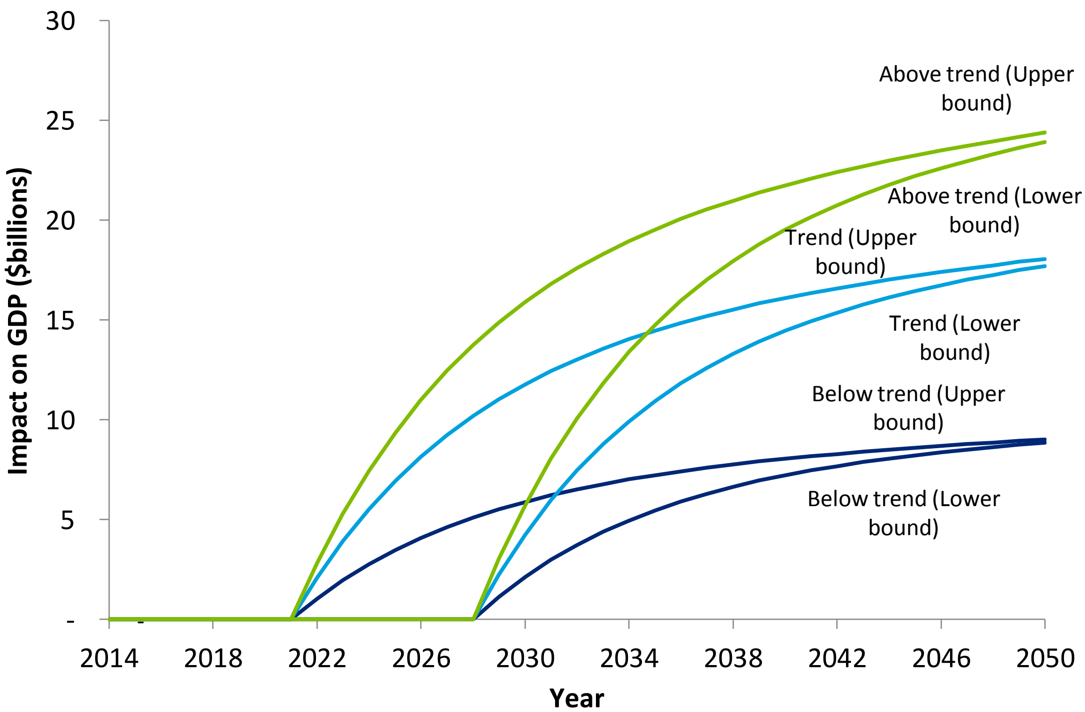
The research expenditure profiles and economic impacts associated with each of these three scenarios are depicted in Chart 5.2 and Chart 5.3 below.

Chart 5.2 Research expenditure profiles under three scenarios



Source: Deloitte Access Economics

Chart 5.3 GDP impacts under three 'research expenditure' scenarios



Source: Deloitte Access Economics

As with the estimates provided for UNSW's research expenditure, these results indicate a return to the economy of between $5 and $10 for each $1 invested in real per capita university research over a period of 35 years (in present value terms). This implies the equivalent annualised return from investments in real per capita university research lies in the order of 60%-100%. By way of comparison, the current annualised real return to paying down government debt is around 1.5% and the historical real before-tax rate of return on private investment is around 7%.

By way of further explanation, these estimates represent the total return of all investments and resulting benefits over a 35 year period. Because of the lag effects in realising returns to benefits from research, in the first few years the returns to investments accumulated over time will be low. However, as the effects of the research mature, these benefits will eventually be highly significant. So, over time, the annual dividend (or equivalent interest payments) on all of the investments made in university research up to that year will increase.

The results from this study suggest that the equivalent average dividend from investments in university research over a period of 35 years is 60-100% annually. So for an equivalent investment of resources to also return 5 to 10 dollars for every dollar invested over 35 years (in present value terms) it would need to pay an annual dividend (an equivalent annual return or 'rate of interest') on cumulative (non-compounded) investments of 60-100%. This annualised return compares very favourably to other forms of investment that may be made over the long term (such as paying down government debt).

In comparison to the results from the faculty investment approach these estimated rates of return are much higher. This likely reflects a number of complex factors, including the fact that top-down analysis of the impact of university research captures the more long-term and diffuse effects of university research which are not effectively captured in micro-economic studies at a firm or industry level.

While these results demonstrate the potentially significant economic consequences of changes to research expenditure, this does not imply that the economy or government should necessarily significantly increase investment in university research. Indeed, there are other long term investments in the economy that these resources could be devoted to, such as infrastructure development, private business investment or paying down government debts.

It should be noted that the government need not be the only source of funding for research universities. This funding can also potentially come from external sources such as private companies, philanthropic organisations and wider society. Further, government funding may help motivate additional streams of funding in research activity. A report by the PACEC and the CBR (2015) notes that public funding can help research universities develop the capacity and capability to attract other sources of funding. Government funding can enable research universities to invest in their capabilities to secure contract research deals, handle contract negotiations, write business proposals, and make knowledge exchange linkages with industry. For example, government funding can initiate high-risk, high-return research activities that would otherwise not have been funded. Once the benefits are proven, the research activities can attract subsequent rounds of funding from external sources.

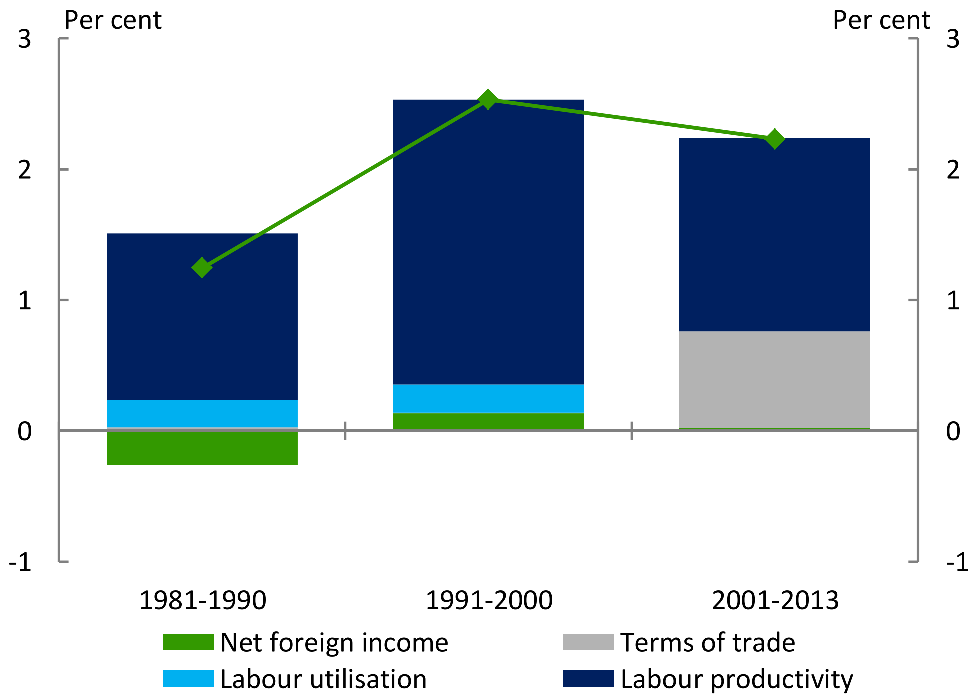
5.2 The productivity imperative

To maintain national income levels and living standards over the coming decades Australia faces a considerable productivity challenge. As commodity prices fall and the returns from the decade long mining boom recede Australia will need to find other areas of economic growth, principally in the form of higher levels of labour productivity.

Indeed, for growth in national income over the next decade to remain at the level experienced from 2001-2013, labour productivity will need to increase by almost 3% annually from 2014 to 2023 – around twice the level of productivity growth experienced between 2001 and 2013.

As shown in Chart 5.4, improvements in the terms of trade contributed 0.74 percentage points to the total average annual income growth of 2.23% during the period 2001-2013. Unfortunately, income effects from terms of trade booms are only temporary. As the terms of trade returns to its historical long-run average over the coming years, it is expected that this same level of income gain will become an income loss. To offset this effect and maintain living standards growth over the next decade the average level of annual labour productivity growth is required to be 2.97% – higher than any level experienced in the past three decades.[50]

Chart 5.4 Annual growth in gross national income per person by source



Source: Deloitte Access Economics estimates using ABS data

[50] Importantly, this assumes that there are also no adverse effects from falling labour utilisation as the population ages, which are also expected but not measured here.

University higher education and research will play a key role in supporting this growth in labour productivity over the coming decades, through impacts on skilled workers and technological progress.

It is estimated that a 10% increase in university research spending (per capita) compared to 2013 levels would increase labour productivity by around 1.8% annually over the long run. Because it takes some time for the productivity effects of increased university research expenditure to affect the economy this 1.8 percentage point impact on labour productivity will not be realised immediately. However, as the effects of increased research expenditure manifest over time, it is estimated that this investment in research would generate almost a third of the required rate of labour productivity growth required to maintain our growth in living standards over the next 35 years.
It should be noted that the results from this analysis rely on the estimated elasticity of research expenditure on economic growth derived from our macro-econometric cross-country model. This model is not without its limitations – set out in section 4.3.2 of this report – which should be considered when interpreting the results from this analysis.

6 Concluding observations – priorities, growth and monitoring

Universities contribute to the achievement of both Commonwealth and State Government economic priorities, and their activities in many ways align with industries that Deloitte Access Economics projects to grow considerably in coming years.

To better understand the economic contribution of universities in the future, knowledge exchange metrics could provide universities with a deeper, more systematic understanding of where the economic (and social) impacts of their research are likely to be most significant, and where these are most amenable to quantification using the methods employed in this study.

This section highlights linkages between UNSW's activities and contributions, and government priorities and growth areas, as well as discussing opportunities for monitoring UNSW's research impacts into the future.

6.1 UNSW and government economic priorities

6.1.1 Commonwealth Government priorities

6.1.1.1 2014-15 Commonwealth Budget

In the 2014-15 Commonwealth budget, the government listed a number of budget priorities. Thematically these were:

- **Building a Stronger Economy through jobs, growth and opportunity**: The focus of this theme is to support employers to create jobs by providing incentives to small businesses through tax breaks and to provide new measure to help the unemployed seek employment.

- **Supporting Australian families**: This theme was focused on providing further support for young children through preschool funding and investments into childcare. Health was another focus of this theme where the government will provide additional funding for new drugs to be listed on the PBS, the medical research fund and for immunisations.
- **A fairer Australia**: The focus of this theme was to review the tax and welfare system to ensure that the tax burden is fairly shared and that welfare payments are targeted towards those that need it most. It also mentions a review of the foreign investment framework and the recovery of HELP loans from those residing overseas.
- **Protecting Australia**: The focus of this was additional funding for national security, in particular for military operations in the Middle East, border protection and investments in IT.

UNSW makes a direct and measurable contribution to each of these areas in different ways.

Building a Stronger Economy through jobs, growth and opportunity

UNSW makes direct and measurable contributions to building a stronger Australian economy through jobs, growth and opportunity in several key ways:

- As this study has found, UNSW's ongoing operations and student expenditure in 2014 contributed 11,700 jobs to the Australian economy. Almost 5,900 staff (FTE) were employed directly by UNSW. As UNSW's teaching and research activity expands, so too will the jobs it contributes to the economy.
- UNSW's research activity supplies knowledge which, if adopted by industry, government and broader society, can lead to the creation of better systems, materials and products, and improved overall productivity. UNSW's 2014 research expenditure of $1.04 billion, sustained in real per capita terms out to 2050, is associated with a total impact on Australia's GDP of around $106-$190 billion (in present value terms).
- In 2014, UNSW provided high-quality education to over 51,000 students. This study estimated that UNSW's 4,900 bachelor degree graduates from 2013 may contribute as much as $204 million to Australia's GDP each year over their lifetimes, equivalent to around $41,500 per graduate, as a result of their university education. The quality of graduates produced by UNSW is also evident in UNSW being the highest ranked Go8 university on teaching quality, and the only Go8 university that has received a 5 star ranking on starting graduate salaries and the likelihood of getting a full-time job.

Supporting Australian families and a fairer Australia

UNSW also supports the government's priority of supporting Australian families and a fairer Australia. This is highlighted by a number of initiatives:

- Scholarship: UNSW provides scholarships that are specifically targeted at low income families to ensure that they have the opportunity to study at UNSW. UNSW is one of the leading providers of equity scholarship in Australia. In 2015 it provided around 70 equity scholarships worth over $200,000.
- Indigenous support: Nura Gili program which support indigenous Australians by providing additional academic support, through additional tutors and other support such as employment within the university. To support indigenous Australians, UNSW also provides 3 equity scholarships worth $10,000 per year for the minimum duration of the program specifically for indigenous Australians.

- Equity and disabilities support: UNSW has an active Student Equity and Disabilities Unit (SEADU) who provide additional support for students with a disability. In addition to academic provisions, SEADU works with the faculty to ensure that provisions can be made for students to ensure that these students feel that they are in an all-inclusive study environment. This ensures that these students can realise their potential.

Protecting Australia

UNSW also contributes to protecting Australia by providing tertiary education to the Australian Defence Force Academy (ADFA). UNSW is unique in this perspective as it is the sole provider of tertiary education to ADFA. In 2015, ADFA had over 2,500 students.

Overall, this suggests that the contribution of UNSW extends beyond that of its economic contribution. UNSW also contributes to some of the Commonwealth government's broader budget priorities.

6.1.1.2 5-Pillar Economy plan

In 2013, the current Government promoted its 5-pillar plan to strengthening the economy as part of the last election. The 5-pillars were:

- Building on our strengths in Manufacturing Innovation: The purpose of this pillar was to reduce red tape for manufacturing businesses, increase productivity provide better links between government, business and research institutions and improve manufacturing innovation.
- Building a world-class Education and Research sector: The purpose of this pillar was to encourage the development of the education and research sector to drive productivity within the economy.
- Building a world-class Mining, Energy and Resources sector: The purpose of this pillar was to reduce red tape and consolidate the strengths of the mining industry.
- Building on our strengths in Agriculture Exports: The purpose of this pillar was to provide better management of water resources to help fuel productivity within the agricultural sector. There were also plans to form stronger links between fishing research and its practical applications.
- Building on our strengths in Advanced Services: The purpose of this pillar was to reduce red tape and promote the use IT as a way to boost productivity in the services sector. It also emphasised the need to prioritise the recommendations from the Johnson report to enable growth and export of the financial services sector.

Building on our strengths in Manufacturing Innovation

UNSW plays a vital role in manufacturing innovation in Australia. This can be seen in previous research projects that have filtered through to manufacturing technologies, current areas of research of strong relevance to innovative manufacturing, as well as UNSW's supply of highly skilled graduates in engineering. To highlight UNSW's strength, it is worth noting that:

- According to Thomson Reuters, since 1980, UNSW is ranked number 1 in terms of the number of research documents produced in the Engineering, Manufacturing category making it the leading contributor in this research area. It is ranked second in terms of citation.

- According to QS, UNSW was Australia's leading university for material science. To highlight, UNSW is one of the few universities to explore 3D printing as a manufacturing technique.

This suggests that UNSW is active in research in this field as well as producing skilled graduates in this area.

Building a world-class Education and Research sector

As this study's assessment of the contributions of UNSW's teaching and research activities has shown, UNSW continues to be one of the leading tertiary education providers and research universities in Australia. It provides quality education to its graduates, is a leading recipient of research grants and is considered to be one of the most research intensive universities in Australia (winning the highest amount of Australian Research Council research project funding in the country – with $45.3 million across three funding schemes).

Building a world-class Mining, Energy and Resources sector

In terms of energy and resources, UNSW makes significant contributions to this sector through its research and skilled graduates.

- According to Thomson Reuters, since 1980, UNSW has the highest number of citations in its research in energy and fuels and is ranked second (by citation) for water resources research;
- UNSW is one of the leading photovoltaics school in Australia, some of its successes include the first 20% efficient solar cells in 1985 and more recently they were able to achieve 25% efficiency through the use of PERL technology. The current commercial variant of this technology has recorded up to US $1 billion in product sales.
- UNSW is also a leader in sustainable mining where one of its faculty members Professor Ros Taplin is the director at the Australian Centre for Sustainable Mining practices.

Building our strengths in advanced services

UNSW is also one of the leading providers in advanced services. To highlight, according to QS, UNSW is ranked in the top three in Australia in the following disciplines:

- Accounting and finance;
- Business and management; and
- Law.

From a research perspective:

- According to the ARWU, UNSW is ranked second in Australia for economics and business.
- In terms of number of citations, according to Thompson Reuters, UNSW is ranked first in terms of business, operations research and management science, management and finance research.

Overall, this suggests UNSW is supplying significant human capital and quality research to support the government's 5-pillars.

6.1.2 NSW Government priorities – 2014-15 Budget

In addition to aligning its activities with the Commonwealth government's budget priorities, UNSW also supports the NSW government's priorities in several ways.

In the 2014-15 NSW budget, the NSW Government listed a number of important budget priorities which included:

- **Accelerating Rebuilding NSW:** delivery of the $20 billion Rebuilding NSW initiative, a plan to promote economic growth and productivity by funding the delivery of major infrastructure projects including public transport, urban and regional roads, water, hospitals, schools, and cultural and sporting infrastructure.
- **More jobs for New South Wales:** $397 million over four years to help create 150,000 jobs, grow local businesses and attract new businesses to New South Wales, including tax rebates and subsidies to incentivise employment, scholarships for students undertaking qualifications for 'technology and growth jobs', and relocation incentives.
- **Election commitments:** improving frontline services for the people of New South Wales, with increased spending for health, education, transport, infrastructure, tourism and police.
- **Housing Acceleration Fund:** funding for critical growth infrastructure projects to significantly accelerate housing supply and address the challenge of housing affordability in priority growth areas.

UNSW supports these priorities in a number of ways which are highlighted below.

6.1.2.1 Accelerating Rebuilding NSW

UNSW's main contribution is its strength in research and it provision of skilled graduates. To highlight:

- QS ranked UNSW's civil and structural engineering school at number 14 globally (highest in Australia), the Times Higher Education Supplement ranked UNSW's engineering and technology program to be 63rd (5^{th} in Australia) and the Academic Ranking of World Universities ranked UNSW's engineering field to be 43 (highest in Australia).
- According to Thomson Reuters, UNSW produced the highest number of research documents in construction and building technology and civil engineering. It was ranked second amongst Australian universities in terms of number of citations.

Overall, these ranking suggest that UNSW is one of the leading civil engineering schools in Australia for aspiring engineers and a leading research contributor in this field.

6.1.2.2 More jobs for New South Wales and election commitments

UNSW is one of the leading providers of graduates in computer science and IT in today's digital economy. It is not only a leading provider but also an important research institution in Australia. UNSW is playing an important role in supporting the government's budget priorities by providing skilled labour and innovation to support its goals in terms of providing skilled graduates for growth and technology sectors. In addition, the embrace of digital technology is also important from an election commitment perspective where one of the NSW government's commitments was to improve the delivery of frontline government services. The importance of this digital strategy is highlighted by the development of the NSW 2012 ICT strategy.

From this perspective, UNSW plays an important role in supporting the government's goals. Some of its achievements include:

- UNSW is one of the leading universities in Australia for engineering, in 2015, QS ranked UNSW's technology and engineering faculty to be 27th (second highest in Australia) and the Academic Ranking of World Universities ranked UNSW to be 43rd (highest in Australia).
- According to Thomson Reuters, UNSW is the leading university in terms of volume and citations for computer science.
- According to QS, UNSW's computer science was ranked at number 35, which was the 3rd highest in Australia.

Based on its strength in IT, UNSW could be a useful catalyst for the NSW government to accelerate its strategy by providing skilled labour and research in this field.

6.1.2.3 Housing Acceleration Fund

The main contribution that UNSW makes to this area is its supply of skilled graduates in civil and structural engineering and its research in this area. It is one of the leading schools in this respect. More specifically:

- According to QS, UNSW was ranked third in Australia for Architecture and second for Art and Design;
- According to Thomson Reuters, in terms of citation in research papers in Art and Architecture, UNSW was ranked third in Australia.

This suggests that in addition it its construction strengths, UNSW can also help to contribute to better design of these properties and help contribute ideas to improving housing supply in Sydney.

6.2 UNSW and economic growth areas

In 2014, Deloitte identified five key industries that were expected to grow quickly in the near term. These were:

- **Agribusiness:** Australia is well positioned to be a major global agricultural producer due to our fresh produce. Water management is critical to ensure that growth in this sector can be realised.
- **Gas:** Australia has significant gas reserves which could be used as a cleaner energy source for our Asian neighbours.
- **Tourism:** Australia is considered to be a unique destination for the region due to its unique landmark, open spaces and fine food and wine.
- **International education:** Australia is seen to be a regional education powerhouse compared to its neighbours.
- **Wealth management:** Australia has a significant expertise in managing retirement wealth funds. As the world gets older there will be increasing demand for these services and Australia is well positioned to capitalise on this due to its expertise and its strong rule of law.

Deloitte predicts that collectively, these five industries could end up growing to be the size of the mining industry.

UNSW provides high-calibre skilled graduates for each of these growth industries. UNSW has a strong reputation in teaching and research in water, energy and resources, as well as business and finance, and is regarded as one of the leading providers of skilled labour in these fields.

UNSW makes particularly strong contributions in international education. UNSW currently has more than 10,000 international students, which is in no small way due to its reputation as an education provider and the quality and impact of the research it generates.

To date, UNSW has been actively seeking to make its offerings attractive to international students. One such area is through adopting new teaching methods. An example is the use of open platforms and gamified education i.e. using games to teach a concept. The School of Economics at UNSW has developed a game in which students interact and develop their economy. In addition to this, UNSW has also made use of more open platforms enabling students to interact in a Facebook like environment and allowing students to participate in a digital community. Innovations such as these are designed to improve both the dissemination of knowledge as well as improve student experience. These and other innovations are part of the reason UNSW will be able to maintain its position as one the leading providers for the international market.

Overall, the evidence suggests that UNSW is well positioned to support the next waves of economic growth, and has made strategic commitments to help ensure that this growth is realised.

6.3 A framework for ongoing monitoring

This study has sought to provide a comprehensive and authoritative assessment of UNSW's economic contributions, particularly those arising from its research efforts. The analysis demonstrates that university research can have highly significant impacts on economic growth, and generate considerable benefits to a broad range of individuals and institutions. However, precisely estimating these contributions below the university level is subject to several limitations, short of undertaking detailed (and time-consuming) case studies which require access to comprehensive financial data.

UNSW's wide array of research projects exhibit heterogeneity in their objectives, characteristics and potential for external adoption. The benefits and impacts of university research are likely to be much broader than what can be readily quantified in an economic sense. Also, while economic modelling typically focus on areas of applied research with tangible results, basic or pure university research can have large economic and social impacts. These impacts can occur through direct impacts on industry and society, as well as indirectly acting as a foundation for more applied research.

The economic contributions of research largely arise from the successful and effective knowledge flows associated with the research, which are typically easier to measure and monitor than economic impacts. As knowledge flows are inexorably linked to the economic contribution of research, knowledge flow metrics are invaluable in corroborating economic contribution estimates. Therefore, knowledge exchange metrics can provide a systematic standard of verification for the economic contributions that arise from university research, providing increased confidence in the returns generated from investment in university research. In some cases, as in the Faculty-investment approach applied to the Faculty of Engineering in this study, the extent of these observable knowledge flows will indicate where economic contributions are amenable to explicit estimation. Such a set of knowledge flow/exchange metrics, applied to the totality of UNSW's research, could position the university to better understand and more effectively communicate its research impacts to policy makers and the wider community.

Already, in the United Kingdom, a system known as the Research Excellence Framework (REF) is used to assess the research of British higher education institutions in order to inform research funding decisions. This, in part, captures the importance of knowledge exchange. Research across a number of disciplines in each university is assessed through a process of expert sub-panel reviews. Research is assessed in terms of their **output** – their 'originality, significance and rigour', with reference to international research quality standards; in terms of their **impact** – their 'reach and significance' on the economy, society and/or culture that were underpinned by the research; and their **environment** - the 'vitality and sustainability' of the research environment, including its contribution to the vitality and sustainability of the wider discipline or research base.

6.3.1 Knowledge exchange metrics

Knowledge exchange metrics are ultimately about finding ways that research universities can articulate the value that they create in society at large through their knowledge exchange activities, which is often done via a Knowledge Transfer Organisation (KTO). The performance indicator metrics for KTOs include things such as number of grants, patent application and patent grants; license income earned; number of spin-offs established; and number of unique private sector entities funding research grants and contracts. Further, some metrics attempt to separately measure the **quantity** of knowledge exchange (e.g. number of licenses) and the **quality** of knowledge exchange (e.g. customer feedback or number of licenses generating income for the end-user).

Below are two examples of knowledge exchange metrics from the United Kingdom and North America that could potentially be adapted for the purposes of assessing the impact of UNSW research, and research by Australian universities in general.

Library House metrics (2008)

In the United Kingdom, there is agreement between UK stakeholders on what should be measured and several government organisations, such as the Higher Education Funding Council for England (HEFCE) and the Higher Education Statistics Agency (HESA), already collect relevant data which can be used to capture knowledge exchange activities conducted by research universities (Library House, 2008).

In the table below, Library House (2008) has summarised a set of existing and potential future metrics for capturing both the quantity and quality of knowledge exchange.

Table 6.1: Quantity and quality metrics for knowledge exchange

Mechanism	Measure of quantity	Measure of quality
Networks	# of people met at events which led to other knowledge exchange activities	% of events held which led to other knowledge exchange activities
Continuing professional development	Income from courses, # of courses held, # people and companies that attend	% of repeat business, customer feedback
Consultancy	# and value/income of contracts, % income relative to total research income, market share, # of client companies, length of client relationship	% of repeat business, customer feedback, quality of client company, importance of client relative to their company
Collaborative research	# and value/income of contracts, market share,% income relative to total research income, length of client relationship	% of repeat Business, customer feedback, # of products successfully created from the research
Contract research	# and value/income of contracts, market share,% income relative to total research income, length of client relationship	% of repeat Business, customer feedback, # of products successfully created from the research
Licensing	# of licenses, income generated from licenses, # of products that arose from licenses	Customer feedback, quality of licensee company, % of licenses generating income
Spin-outs	# of spin-outs formed, revenues generated, external investment raised, market value at exit (IPO or trade sale)	Survival rate, quality of investors, investor/customer satisfaction, growth rate
Teaching	Graduation rate of students, rate at which students get hired (in industry)	Student satisfaction (after subsequent employment), employer satisfaction of student
Other measures	Physical Migration of Students to Industry, Publications as a Measure of Research Output	

Source: Library House (2008)

CICEP New Metrics

In North America, The Association of Public and Land-grant Universities (APLU) has a Commission on Innovation, Competitiveness, and Economic Prosperity (CICEP) who are responsible for the "New Metrics" project to develop how universities measure their contributions to regional and national economic growth (APLU, 2014). The CICEP New Metrics shown below are a set of 20 metrics which help frame a university's economic significance.

Table 6.2: CICEP New Metrics

Mechanism	Questions
Sponsored Research by Industry	1. Number of grants, contracts and sub-agreements from private sector entities 2. Dollar value of industry-sponsored research expenditures 3. Number of sponsored research projects by industry sector 4. Dollar value of sponsored research expenditures by industry sector 5. Number of individual private sector entities funding research grants and contracts
Human Clinical Trials (for universities with medical, nursing, and/or pharmacy programs)	6. Number of active trials, by phase, during the reporting period 7. Number of subjects enrolled in clinical trials over the past 12 months 8. Total dollar value of sponsored research grants for which clinical trials were conducted 9. Number of protocols approved during the time period 10. Number of trials initiated during the time period
Service to External Clients	11. Number of organizations served 12. Number of companies that provided on-site technical services
Student Employment on Funded Projects	13. Number of students paid through externally funded grants or contracts
Student Entrepreneurship	14. Number of entrepreneurship courses/programs (credit and non-credit) 15. Number of entrepreneurship courses/programs requiring a capstone project 16. Number of student start-ups associated with courses, programs, competitions, clubs, university incubators, or other university-affiliated organizations
Alumni in the Workforce	17. Average wages of alumni living in-state
Incubation and Acceleration Program Success	18. Number of full time equivalent employees

Ability to Attract External Investment	19. Dollar amount of (equity) capital raised by clients and graduates from investors 20. Dollar amount of funding received from federal, state, or foundation sources; state or local matching programs; or other non-private sources

Source: APLU (2014)

Developing such a set of knowledge exchange metrics, for application to the totality of UNSW's research, could position the university to more thoroughly understand and more effectively communicate the likely impacts of its research, and identify where the economic contributions of this research could reliably be estimated (similar to the faculty-investment approach in this study).

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Appendix A: Econometric modelling approach

In line with a large body of economic development literature, this report seeks to diffuse effects of human capital and higher education research and development (R&D) on economic growth using a neo-classical production function; the formal framework is first set out by Mankiw et al (1992) and its augmented-form implemented by Bassanini and Scarpetta (2001). The models used in this report adhere closely to the existing literature, with modifications provided to accommodate the focus on tertiary human capital and higher education R&D. The standard neo-classical growth model is derived from constant returns to scale production function with three inputs (capital, labour and human capital) that are paid their marginal products. Production (output) at time t is given by:

$$Y(t) = K(t)^{\alpha} H(t)^{\beta} \big(A(t)L(t)\big)^{1-\alpha-\beta}$$

Where Y, K, H and L are respectively output, physical capital, human capital and labour, α is the partial elasticity of output with respect to physical capital, β is the [atrial elasticity of output with respect to human capital and $A(t)$ is a measure of technological progress and economic efficiency.

$$A(t) = I(t)\Omega(t)$$

This research incorporates higher education R&D along with other R&D activities and exposure to international trade as key determinants of economic efficiency $I(t)$.

$$\ln I(t) = p_0 + \sum_j p_j \ln V_j(t)$$

$$\ln I(t) = \ p_0 + p_1 Higher\ Education\ R\&D\ + p_2 Other\ R\&D + p_3 Exposure\ to\ trade$$

Technological progress is assumed to be exogenous and grows at rate $g(t)$.

$$\dot{\Omega}(\mathrm{t})\ = g(t)\Omega(t)$$

Substituting the steady-state values of physical capital and human capital yields the intensive form of steady-state output as a function of h^*.[51]

$$\ln(y^*) = \ln\Omega(t) + p_0 + \sum_j p_j \ln V_j(t) + \frac{\alpha}{1-\alpha}\ln s_k(t) + \frac{\beta}{1-\alpha}\ln h^*(t) - \alpha(1-\alpha)\ln\big(g(t)+n(t)+d\big)$$ [52]

[51] The steady-state stock of human capital h^* is not observed, it can be expressed as a function of actual human capital: $\ln h^*(t) = \ln h(t) + \frac{1-\psi}{\psi}\Delta\ln\left(\frac{h(t)}{A(t)}\right)$

The above is valid in empirical cross-country analysis only if countries are in their steady states or if deviations from steady state are independent and identically distributed. If observed growth rates include out-of-steady-state dynamics, then the transitional dynamics have to be modelled explicitly (Bassanini and Scarpetta, 2001). A linear approximation of the transitional dynamics can be expressed as follows (Mankiw et al, 1992):

$$\begin{aligned}\Delta \ln y(t) = -\phi(\lambda) \ln y(t-1) + \phi(\lambda) \left(\frac{\alpha}{1-\alpha}\right) \ln s_k(t) + \phi(\lambda) \left(\frac{\beta}{1-\alpha}\right) \ln h(t) \\ + \sum_j p_j \phi(\lambda) \ln V_j(t) + \frac{1-\psi}{\psi} \left(\frac{\beta}{1-\alpha}\right) \Delta \ln h(t) \\ - \phi(\lambda) \left(\frac{\alpha}{1-\alpha}\right) \ln(g(t) + n(t) + d) + \left(1 - \frac{\phi(\lambda)}{\psi}\right) g(t) \\ + \phi(\lambda)(p_0 + \ln \Omega(0)) + \phi(\lambda) g(t) t\end{aligned}$$

This equation represents the generic functional form that has been empirically estimated in this research. Further, the coefficient estimate $\phi(\lambda)$ represents the convergence parameter. The convergence parameter underlines the speed in which countries converge to their steady-state output.

In addition to estimating the stead state solutions, we also estimate another functional form, adding short-term dynamics in the model to help isolate dynamic cyclical effects. This augmentation is advantageous as it relaxes the assumption that countries are in their steady states and that deviations from the steady state are independent and identically distributed. Its functional form can be expressed as follows:

$$\begin{aligned}\Delta \ln y(t) = a_0 - \phi \ln y(t-1) + a_1 \ln s_k(t) + a_2 \ln h(t) - a_3 n(t) + a_4 t + \sum_{j=1}^{3} a_{j+4} \ln V_j \\ + b_1 \Delta \ln s_k(t) + b_2 \Delta \ln h(t) + b_3 \Delta \ln n(t) + \sum_{j=1}^{3} b_{j+3} \Delta \ln V_j\end{aligned}$$

Similar to specifications used in Bassanini and Scarpetta (2001), our analysis uses a sample of 37 countries between 1980 and 2010 (Table A.1). Where appropriate, data is converted to constant 2010 US dollars using constant Purchasing Power Parity, consistent with OECD standards.

[52] Where y^* is the steady-state output per capita, s_k is the investment rate in physical capital, $n(t)$ is the population growth rate, and d is the rate of depreciation.

Table A.1: Countries

Country list				
Australia	Denmark	Iceland	Mexico	Slovak Republic
Austria	Estonia	Ireland	Netherlands	Slovenia
Belgium	Finland	Israel	New Zealand	South Africa
Canada	France	Italy	Norway	Spain
Chile	Germany	Japan	Poland	Sweden
China	Greece	Korea	Portugal	Switzerland
Czech Republic	Hungary	Luxembourg	Russia	Turkey
United Kingdom	United States			

Table A.2 outlines the parameters used in the estimation procedure.

Table A.2: Data sources

Parameter	Variable	Source
$y(t)$	Gross domestic product per capita	OECD
$h(t)$	Tertiary education attainment (% of 15+ population)	Barro-Lee (2010)
$n(t)$	Total population growth	OECD
$s_k(t)$	Gross capital formation (% of GDP)	OECD
$V_1(H\ R\&D)$	Expenditure on Higher education R&D per capita	OECD
$V_1(O\ R\&D)$	Expenditure on Other R&D per capita	OECD
$V_3(Trade)$	Exports and Imports of goods and services (% of GDP)	World Bank
t	Time trend	-

Table A.3 outlines the modelling results.

Table A.3: Modelling results

Parameter	Model I: Steady State	Model II: Short term dynamics
$\ln y(t-1)$	-0.204**	-0.149**
$\ln s_k(t)$	0.819***	0.454***
$\ln h(t)$	0.152*	0.233**
$n(t)$	-12.07*	-7.621
$V_1(H\ R\&D)$	0.175*	0.184***
$V_2(O\ R\&D)$	0.139*	0.150*
$V_3(Trade)$	0.123	0.128
$\Delta \ln s_k(t)$	-	0.162***
$\Delta \ln h(t)$	-	-0.0864
$\Delta n(t)$	-	0.265
$V_1(H\ R\&D)$	-	0.0731***
$V_2(O\ R\&D)$	-	0.174***
$\Delta V_3(Trade)$	-	-0.0425

Note: * p<0.05, ** p<0.01, *** p<0.001. Reported coefficients are transformed to exclude the convergence term per their functional form.

Production parameters

Estimates of steady state coefficients as well as parameters of the production function can be retrieved based on the estimated coefficients presented above. For example, according to the functional form of the linear approximation given by Mankiw et al (1992), the share of physical capital in steady-state output (α) is given by the coefficient estimate physical capital investment rate (s_k) and the convergence term (ϕ):

$$a_1 = \phi\left(\frac{\alpha}{1-\alpha}\right)$$

Table A.4 outlines the implied input shares of the estimated production function.

Table A.4: Countries

Implied share	Model I	Model II
Physical capital share (α)	45.02%	31.22%
Tertiary human capital share (β)	8.36%	16.02%
Residual share ($1-\alpha-\beta$)	46.62%	52.75%

Our results indicate the average share of tertiary human capital is around 12.2%, that is, around 12% of steady-state output can be attributed to tertiary human capital inputs.

Elasticities

The estimated coefficients can be interpreted as an elasticity on steady-state GDP. For example, the steady-state effect of higher education R&D has the functional form of ϕp_j where ϕ is the estimated coefficient for $\ln y(t-1)$. p_j then represents the elasticity of higher education R&D on steady-state output, estimated to be around 0.175 under model I and 0.184 under model II. This implies that a 10% increase in higher education R&D per capita will increase steady-state output by 1.75% – 1.84%.

Convergence

The convergence parameter ϕ plays an important role in explaining the modelling results. In all specifications the convergence parameter is significant, suggesting a (conditional) process of convergence as countries move towards their steady-state output levels. For example, under model II, the convergence term is estimated to be 0.149, this indicate that the economies will close 14.9% of the gap between their current level of output and their steady-state output. The convergence process is asymptotic, meaning that countries will never truly reach their steady-state levels but rather move very close to it.

Appendix B: Estimates of R&D returns

Table 6.3: Examples of published estimates of public R&D returns

Paper	Focus	Estimated rate of return
Griliches (1958)	Hybrid corn	21-40%
Griliches (1964)	Agriculture	35-40%
Peterson (1967)	Poultry	21-25%
Evenson et al (1978)	Agriculture	45%
Knutson and Tweeten (1979)	Agriculture	28-47%
Scobie and Everleens (1986)	Agriculture	30%
Mansfield (1991)	Academic science	28%
Nadiri and Mamuneas (1994)	Manufacturing	6-9%
Mullen and Cox (1995)	Broadacre agriculture	15-40%
Mullen, Cox and Hu (1997)	Broadacre agriculture	12-20%
Mamuneas (1999)	High-tech manufacturing	12-21%
Toole (1999)	Pharmaceuticals	11-32%
Schimmelpfennig and Thirtle (1999)	Agriculture	10-60%+
Thirtle (1999)	Sugar	20-50%
Cockburn and Henderson (2000)	Biomedical science	30% +
Barnes (2002)	Agriculture	19-23%
Scobie and Hall (2006)	Agriculture	0-32%
Hall and Scobie (2006)	Agriculture	17%
Mullen, Scobie and Crean (2006)	Agriculture	13-21%
Johnson, Razzak and Stillman (2007)	Nine industries	Statistically insignificant
Onofri and Fulginiti (2008)	Agriculture	190%
Hosseini, Hassanpour and Sadeghian (2009)	Sugar	32%
Access Economics (2008)	Health	117%
Jacob and Lefgren (2007)	Scientific productivity	7-20%
Mamatzakis (2009)	Food and beverage industry	7.3-8.7%

Source: See references

Table 6.4: Examples of published estimates of private R&D returns

Paper	Focus	Estimated rate of return
Terleckyj (1974)	US industries	0-30%
Mansfield (1980)	US chemical and petroleum	27%
Scherer (1982)	US manufacturing	13-29%
Clark and Griliches (1984)	US manufacturing	20%
Griliches and Lichtenberg (1984)	US manufacturing	4-30%
Mansfield (1988)	Japanese industries	42%
Goto and Suzuki (1989)	Japanese manufacturing	22-56%
Sterlacchini (1989)	UK manufacturing	10-30%
Lichtenberg and Siegel (1991)	US firms	13%
Hall and Mairesse (1995)	French firms	6-34%
Jones and Williams (1998)	US manufacturing	35%

Source: See references

Table 6.5: Examples of published estimates of Australian and international aggregate R&D returns

Paper	Focus	Estimated rate of return
Dowrick (1994)	Australian aggregate study	150%
Rogers (1995)	Australian aggregate study	<0%
Bodman (1998)	Australian aggregate study	>200%
Frantzen (2000)	Panel of OECD countries	60%
Louca (2003)	Australian aggregate study	173% in 1990; 116% in 1999
Connolly et al. (2004)	Australian aggregate study	150%
Luintel and Khan (2005)	International panel data	Business R&D spillover rate of 40% for Australia
Gans and Hayes (2006)	Panel of OECD countries	Implied spillover rate of 300% for Australia

Source: See references

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