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FOREWORD

Science, technology, engineering and mathematics, referred to as STEM, are central to our future because of their role in securing Australia's competitiveness in a rapidly changing world. The Prime Minister, the Hon. Tony Abbott MP, acknowledged this on 11 June 2014, when he said, '… *science is at the heart of a country's competitiveness, and it is important that we do not neglect science as we look at the general educational and training schemes*'.

In view of the central importance of STEM, we need to know how we perform. We need to get 'a fix' on our performance—not an easy one, against 'the world', but a more challenging one, against nations that, like us, are essentially free-market economies with serious science engagement. We often depict Australia as 'punching above its weight' in research performance, with about 3 per cent of research outputs from 0.3 per cent of the world's population. But approximately 90 per cent of all STEM research publications are attributed to roughly 15 per cent of countries and 90 per cent of citations are attributed to approximately 13 per cent of countries. Where we stand relative to 'the world' is of marginal value only, serving mainly to direct our attention from where it should be, which is on how to improve.

STEM is a global enterprise. As nations with which we collaborate and compare ourselves take planned, often urgent, action to improve their STEM base, we must be alert to the changes and decide what we ourselves want to do. In order to make wise choices, however, we need to know the baseline from which we start and have a view about where we want to be within a reasonable time.

This report provides insights into where we are and will help us decide what we should do. As an analysis mostly at a high level—signposts in kilometres not metres, let alone centimetres—it is intended to highlight performance and trends that might warrant further investigation, prompt questions for government and contribute to discussion on the future shape and scale of Australian STEM.

The report is about encouraging wise decisions, not about making them. Used well, it will help us improve and help us position Australia in a changing world.

I thank the staff of the Office of the Chief Scientist for their work in developing this report.

Professor Ian Chubb AC
Chief Scientist for Australia
November 2014

SUMMARY

The summary table on the next page provides the key data for international comparisons in the report. For the range of indicators used in this study, it shows which comparator countries are ahead of Australia and which are behind.

When compared with 11 Western European countries, the United States and Canada, Australia performs well in the share of the world's top 1 per cent of cited research papers in STEM. Our best compare well with the best in these countries, but our average field-weighted citation rates are below all of them.

Multiple lines of evidence point to Australia's opportunity to improve performance in STEM. Our international patenting profile is poor, and the level of collaboration between our researchers (approximately 60 per cent of them in universities) and business is one of the lowest in the OECD. Australia sits near the middle of the comparator group for research funding and international collaboration and for primary and secondary students' performance in science and mathematics literacy.

Above Australia | Below Australia | No data available

Europe: Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Norway, Sweden, Switzerland, United Kingdom; Canada, New Zealand, United States; Asia: China, India, Indonesia, Japan, Malaysia, Philippines, Singapore, South Korea, Thailand, Vietnam

Indicators	Time point	Australia	Australian trend	No. of countries above Australia	No. of countries below Australia	No. of countries with no data	Australia's ranking	Total countries	% countries below Australia
Research performance									
Total STEM publications	2002–2012	429 161		9	15	0	10	25	63
STEM citation rate (field-weighted)	2002–2012	1.12		13	11	0	14	25	46
Highly cited research									
Share of top 1% cited publications in natural science and engineering publications	2010–2012	5.5%	↑	6	12	6	7	19	67
Per capita contribution to top 1% cited natural science and engineering publications	2012	10.6	↑	7	9	8	8	17	56
Top cited researchers per million population	2014	2.89		5	19	0	6	25	79
Patents									
PCT patent applications (by inventor)	2011	1 640	↓	9	9	6	10	19	50
Triadic patent families	2011	209	↓	14	4	6	15	19	22
Percentage of PCT patent applications with foreign co-inventors	2011	16.7%	↑	15	5	4	16	21	25
Research funding									
Contribution to global expenditure on R&D	2010	2.0%	↑	8	10	6	9	19	56
GERD as a share of GDP	2010	2.2%	↑	9	8	7	10	18	47
International collaboration									
Percentage of internationally co-authored publications	2002–2012	49.8%		15	7	2	16	23	32
Citation rate (field-weighted) for international collaboration	2002–2012	1.27		13	10	1	14	24	43
Share of internationally co-authored publications in top 1% of natural science and engineering	2010–2012	66.4%	↑	13	5	6	14	19	28
Proportion of internationally co-authored BCH publications	2002–2012	44.9%		14	9	1	15	24	39
Citation rate (field-weighted) for internationally co-authored BCH publications	2002–2012	1.30		13	10	1	14	24	43
The STEM research workforce									
FTE researchers	2008	92 649	↑	8	10	6	9	19	56
Researchers per 1000 total employment	2008	8.50	↑	8	8	8	9	17	50
Proportion of researchers employed in business sector	2011	32%		15	0	9	16	16	0
Higher education									
Students in tertiary education (first degree/bachelors) per 100 000 population	2010	5 884		2	9	13	3	12	82
Proportion of tertiary students (first degree/bachelors) in STEM	2009	10.6%		11	3	10	12	15	21
Students enrolled in tertiary science degrees per 100 000 population	2010	526		5	6	13	6	12	55
Science and engineering doctorate graduates per 100 000 population	2010	10.2		8	7	9	9	16	47
Schools									
PISA mathematical literacy mean score	2012	504	↓	8	10	6	9	19	56
PISA scientific literacy mean score	2012	521		6	12	6	7	19	67
Legislated proportion of time spent teaching science in primary education	2011	5.7%		9	2	13	10	12	18
Legislated proportion of time spent teaching mathematics in primary education	2011	17.4%		3	9	12	4	13	75

CONTENTS

TABLES

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CHAPTER 1

1. INTRODUCTION

In March 2014 the Office of the Chief Scientist initiated a benchmarking report on Australian science, technology, engineering and mathematics, or STEM. The results detailed in the report were developed to provide the following:

- a broad evidence base to guide government and public discourse on Australian STEM
- a baseline for monitoring any impacts of future changes in STEM focus or strategy
- a foundation for further analysis and future benchmarking studies of Australian STEM.

What follows is a comprehensive assessment of Australian STEM by benchmarking wherever possible with STEM in countries with similar governance systems and economic characteristics, as well as those with a rapidly rising STEM capability in the Asia–Pacific region.

The report examines the characteristics and outputs of Australian STEM based on indicators that allow international comparability. The main elements considered are research outputs in STEM, funding for STEM research and development, international collaboration in STEM research, Australia's STEM workforce, and STEM education in schools and higher education institutions.

1.1 WHAT IS STEM?

STEM refers to science, technology, engineering and mathematics. The basic contributors to healthy STEM are research, international engagement and education.

Research supplies a flow of new ideas and knowledge and underpins the development of new and better products and services. International collaboration allows knowledge to be circulated throughout the global community, both for domestic benefit and in order to position Australia as an important and able partner in a changing world. Education prepares a skilled and dynamic STEM workforce and sets the foundations for lifelong STEM literacy in the community, shaping perceptions of the role of STEM in society.

Australian STEM therefore must contribute people, knowledge, products and services to a world that relies increasingly on the continuous production and application of ideas leading to higher productivity, more and better jobs, and increased competitiveness.

1.2 THE SCOPE OF THE PROJECT

This report builds on a previous report by the Office of the Chief Scientist, the *Health of Australian Science* report, which provided an assessment of the strengths and vulnerabilities of Australia's science capability. The present report extends, deepens and updates the analyses in the *Health of Australian Science* report. It takes guidance from similar international benchmarking reports produced in the United States, Europe and elsewhere that document indicators for the performance of national and international STEM (see, for example National Science Foundation 2014). The data presented here are drawn from a variety of sources.

Two groups of nations were identified for the purpose of benchmarking—countries at stages of development similar to that of Australia and with similar governance systems (the United States, Canada and selected European nations) and selected countries in the Asia–Pacific region. The 11 European nations chosen for comparison are Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Norway, Sweden, Switzerland and the United Kingdom (referred to as the EU11). The comparator countries from the Asia–Pacific region are China, India, Indonesia, Japan, Malaysia, the Philippines, Singapore, South Korea, Thailand, Vietnam and New Zealand.

National data for all comparator countries were not available for the variety of indicators and from the data sources used. The countries compared in each chapter are therefore listed.

Among the primary indicators used in this report are number, citation rates and international authorship of STEM research publications; funding for STEM research and development; researchers in the workforce; enrolments and completions in STEM in higher education institutions; school students' performance in standardised international tests in mathematics and science; and rates of high school students' participation in mathematics and science.

This is a benchmarking study, with all the caveats and potential flaws that come with such a study. Because responsibility for monitoring actions and outcomes across fields of STEM activity is currently split across levels and portfolios of government, our national data sets are imperfect: they were designed for different purposes. The tools we need for tracking our progress should be improved.

The report places emphasis on research publications, which are generated primarily by the higher education sector. This focus reflects higher education's pivotal role in Australia's contribution to the global stock of knowledge and as a major source of innovation. Further, more than 60 per cent of Australia's researchers are employed in the higher education sector; less than 30 per cent are in business (see Chapter 7).

This report does not cover the following:

- STEM training obtained through the vocational education and training system
- collaboration between domestic businesses and researchers in public sector institutions and universities in detail
- measures of innovation other than patents.

1.3 REPORT STRUCTURE AND DATA SOURCES

The report is divided into chapters based on the broad elements of STEM in Australia. Table 1-1 shows the main data sources and indicators used for each chapter.

Table 1-1 Main data sources and indicators used, by chapter

Chapter	Data sources	Indicators
2 Research performance	InCites Scopus	Citation rate (field-weighted) Web of Science publications Share of Web of Science publications Elsevier publications
3 Highly cited research	InCites Scopus	Citation rate (field-weighted) Web of Science publications Share of Web of Science publications Elsevier publications
4 Patents	OECD Patent Database OECD STI Scoreboard	Patent Cooperation Treaty patent applications filed Share of PCT patent applications filed with an international co-inventor Triadic patent families
5 Research funding	OECD Main Science and Technology Indicators Database ABS R&D statistics InCites	Business expenditure on R&D Gross expenditure on R&D as a percentage of GDP Higher education expenditure on R&D Web of Science publications Citation rate (field-weighted)
6 International collaboration	InCites	Web of Science publications Internationally co-authored publications Citation rate (field-weighted) Category citations
7 The STEM research workforce	OECD Main Science and Technology Indicators Database	Number of researchers (full-time equivalent) Share of researchers in business, higher education and government Temporary Work (Skilled) visas (subclass 457) issued in major STEM industries
8 Higher education	Department of Education UNESCO	Higher education enrolments Higher education completions International tertiary comparisons
9 Schools	OECD Trends in International Mathematics and Science Study Australian Council for Educational Research	Mathematics and science literacy Teaching time allocated to science and mathematics Teacher qualifications Rates of Year 12 participation in science and mathematics

CHAPTER 2

2. RESEARCH PERFORMANCE

This chapter analyses the publication output of Australia's science, technology, engineering and mathematics research. The number of publications is an important indicator of STEM research output, while citations provide an indication of the influence of the published research.

2.1 MAIN FINDINGS

- Field-weighted citation rates for Australian STEM publications are higher than the world average in 10 out of the 11 fields of research but are below the average of selected European countries in seven.
- Field-weighted citation rates at a national level for Australian STEM publications are higher than those for our neighbours in Asia, but China, Japan, India and South Korea each produce greater numbers of publications than Australia.
- In terms of articles published, Australia's largest output is in the field of biomedical and clinical health sciences.
- There are 25 sub-fields for which Australian publications are cited more than US publications, and in 47 out of a total of 91 sub-fields Australian publications are cited more than those for the selected European countries. Of these fields, 20 are cited more highly than those for both the United States and the selected European countries.

2.2 BACKGROUND

Bibliometrics involves the application of quantitative analysis and statistics to publications such as journal articles and their accompanying citation counts (Thomson Reuters 2008). Bibliometric analyses of peer-reviewed publications provide insights into how research findings are shared and credited by other researchers and how they influence the global research effort.

Measuring the quantity and quality of publications implied by citations helps us understand Australian STEM—how Australia focuses its research efforts and how it compares with other countries. Publication measurements can also indicate the research quality and performance of individual fields at the national level.

Comparing research output across fields can provide an indication of whether a country has broad-based strengths or has research capability in niche areas of expertise. This helps us develop an understanding of how Australia's research capacity is structured and where our capability is concentrated (West 2013).

Citations represent formal acknowledgment by authors that their own research was influenced by the work of others. They can indicate the influence of a specific publication. Measuring citations can thus show which publications, fields and nations are producing the most influential research.

This chapter examines Australia's STEM research and compares it with that of countries of interest using the following indicators:

- output of STEM publications
- field-weighted citation rates.

2.3 FIELDS OF RESEARCH

Research activity is categorised according to its field. The field of research, or FoR, classification scheme is published by the Australian Bureau of Statistics and funded in part by the Australian Research Council (ABS 2008). In this report the term 'field' denotes FoR two-digit codes and 'sub-field' denotes FoR four-digit codes (see Appendix A). It is the method used in a research area that determines its field. Fields are based on a broad academic discipline (for example, mathematics) and the sub-fields are those that share the same broad method, techniques and/or perspectives as others in the field (for example, pure mathematics, applied mathematics and statistics).

2.4 FIELD-WEIGHTED CITATION RATES

Different fields (and publication types) have different average citation rates. Simply relying on total citations can bias an analysis towards fields that publish more frequently. Weighting citations over time and for each field takes account of differing behaviours—differing publishing and citing cultures. This is referred to as field-weighted citation—or relative citation impact—and is a measure of the actual citations received compared with the citations expected on the basis of the average of the field. Except where noted, in this report all citations are field-weighted to enhance comparability between fields.

2.5 DATA SOURCES AND TERMINOLOGY

The InCites bibliometric database was used to analyse details of all publications in the Thomson Reuters Web of Science database. The database enables direct comparisons within and between fields and sub-fields. It also allows comparison between points in time so as to track national performance within individual fields. International comparisons are generated from a global data set for publications and citations for selected countries or groups of countries. The data can be analysed at the sub-field level to identify trends and areas of relative strength and weakness between nations and STEM fields.

The analyses in this chapter are based on Thomson Reuters InCites data from 2002 to 2012, with national aggregates calculated as a mean across fields of research. This 11 year window was chosen to capture the trajectory of citations for STEM fields, which typically accrue over time, and stabilise 8–10 years after publication (Office of the Chief Scientist 2012). National average citations for this period may mask citations from rapidly emerging fields and countries during the latter part of the period—a subject for further study.

This report uses fields with the two-digit codes 01 to 10 and 11 to constitute STEM. The latter (11) is limited to the Excellence in Research for Australia field cluster 'Biomedical and Clinical Health Sciences'. The purpose of this is to exclude sub-fields that are outside the scope of STEM but are included in the broader medical and health sciences field (which includes biomedical and clinical health sciences). Appendix A provides details.

The InCites database includes articles, editorials, meeting abstracts, proceedings papers and reviews from more than 11 000 scholarly journals. In the present report 'publication' means any publication in the database.

2.6 COUNTRIES ANALYSED

As described in Section 1.2, two groups of nations were identified for benchmarking—countries at stages of development similar to that of Australia and with similar governance systems (the United States, Canada and selected European nations), and selected countries in the Asia–Pacific region.

This chapter provides data of comparator nations from our region (New Zealand, China, India, Indonesia, Japan, Malaysia, the Philippines, Singapore, South Korea, Thailand and Vietnam) and 11 European nations (Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Norway, Sweden, Switzerland and the United Kingdom).

Simply using citations includes multiple counts of a collaborative publication and its attribution—as would happen if a Dane publishes with a Swede—the paper and its citations would be attributed to each country. To avoid this artefact we compare countries against a standard based on aggregated citation data from the EU15 nations (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom) supplied by the InCites database. Though this group of countries does not match our EU11 comparator nations, and excludes high performing countries (Switzerland and Norway), it provides a robust benchmark by avoiding the double-counting of collaborative European publications and their citations.

2.7 HOW DOES AUSTRALIA'S STEM RESEARCH PUBLICATION OUTPUT COMPARE INTERNATIONALLY?

Australian STEM researchers produced 430 000 publications between 2002 and 2012, including about half with at least one international co-author (see Table 6-1). Publications with an international co-author are attributed to the country of each author. Australia's total STEM publications represent 2.2 per cent of global STEM publication attributions, and a ranking of tenth on this measure (see Table 2-1). The United States and China have the two highest shares of publication attributions (20.9 and 9.4 per cent respectively); they are followed by Japan and Germany (at 6 per cent each).

Table 2-2 shows the share of publications, by STEM field, attributed to Australia in the period 2002 to 2012.

Australia's STEM research has an emphasis on the biomedical and clinical health field, with 106 949 publications in 2002 to 2012 (3.4 per cent of the world's publications in this field). Biological sciences is the next largest, with 72 213 publications (4.1 per cent); this is followed by engineering, with 62 112 publications (2.5 per cent). The field of environmental science contributes more to the proportion of global publications than any other Australian STEM field, with 7.5 per cent of all environmental science publications in the world.

Table 2-1 STEM publications attributed to each country, 2002 to 2012

Rank	Country	Total publications	% of world total attributions
	World	13 982 435	
	World attributions	19 187 672	
1	United States	4 016 633	20.9
2	China	1 812 176	9.4
3	Japan	1 142 652	6.0
4	Germany	1 141 690	6.0
5	United Kingdom	1 055 391	5.5
6	France	834 071	4.3
7	Canada	641 110	3.3
8	South Korea	486 059	2.5
9	India	450 616	2.3
10	Australia	429 161	2.2
11	Switzerland	266 500	1.4
12	Sweden	256 940	1.3
13	Belgium	206 480	1.1
14	Denmark	146 323	0.8
15	Austria	142 086	0.7
16	Singapore	127 758	0.7
17	Finland	116 131	0.6
18	Norway	101 200	0.5
19	New Zealand	83 148	0.4
20	Ireland	68 770	0.4
21	Thailand	54 402	0.3
22	Malaysia	45 532	0.2
23	Vietnam	13 228	0.1
24	Indonesia	10 998	0.1
25	Philippines	8 735	0.0

Notes: Total STEM publications are calculated as the sum of publication counts in the ERA 2012 FoR Level 1 categories mathematical sciences, physical sciences, chemical sciences, earth sciences, environmental sciences, biological sciences, agricultural and veterinary sciences, information and computing sciences, engineering and technology, and the biomedical and clinical health sciences subset of medical and health science. The world publication counts were extracted directly from InCites. Publications with international co-authors are attributed to the country of each author. World total attributions (19 187 672) are calculated as the sum of publication attributions for each country.

Source: InCites, Thomson Reuters (2012). Global Comparisons Dataset, 2002–2012. Report created 12 January 2014; data processed 3 July 2013. Data from Web of Science.

Table 2-2 STEM publications by field, 2002 to 2012

Field	Australia		World total
	Total	% world	
All STEM publications	429 161	3.07	13 982 435
Biomedical and clinical health sciences	106 949	3.36	3 179 977
Biological sciences	72 213	4.12	1 754 641
Engineering	62 112	2.46	2 521 292
Chemical sciences	36 880	1.98	1 858 227
Physical sciences	34 375	2.26	1 523 329
Agricultural and veterinary sciences	30 553	4.97	614 921
Environmental sciences	20 944	7.49	279 683
Mathematical sciences	20 123	2.15	935 577
Earth sciences	18 917	5.00	378 670
Information and computing technology	17 599	3.13	562 889
Technology	8 496	2.28	373 229

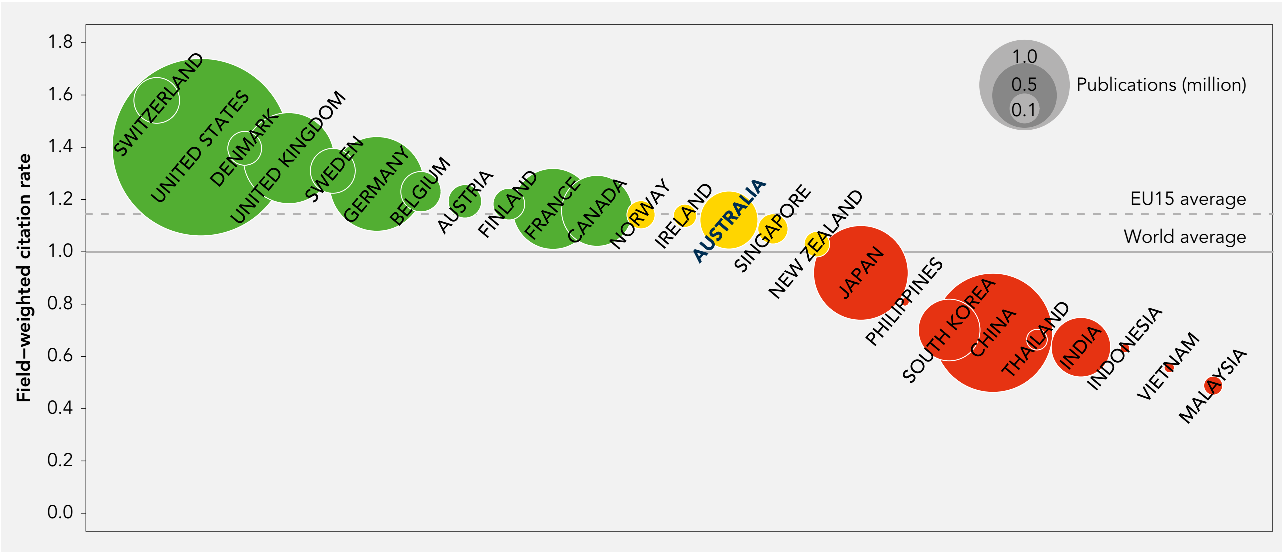
Source: InCites, Thomson Reuters (2012). Global Comparisons Dataset, 2002 to 2012. Report created 12 January 2014; data processed 3 July 2013. Data from Web of Science.

2.8 ARE AUSTRALIA'S STEM RESEARCH PUBLICATIONS INFLUENTIAL?

Figure 2-1 shows both the field-weighted citation rate and the total number of STEM publications for each country analysed. This is an average of all the indicated STEM fields for each country. The figure provides a high-level comparison of the STEM influence of each country but masks individual fields and sub-fields. Subsequent figures provide more detailed comparisons of fields for all countries in this analysis (Figure 2-2 and Figure 2-3) and at the level of sub-fields for Australia (Figure 2-4).

Overall, the level of citations for Australian STEM publications is lower than that for all of the European countries assessed and for the United States and Canada. Australian STEM publications do, however, receive more citations than publications from our Asian neighbours, although citations at the national level for STEM publications from many Asian nations are below the world average.

Figure 2-1 International STEM research, 2002 to 2012: Australia in context



Notes: Publication counts are Web of Science documents classified as article, note or review, by year of publication and assigned to a country based on the institutional address(es) listed in the publication. STEM fields were selected using Australia ERA 2012 FoR Level 1 categories mathematical sciences, physical sciences, chemical sciences, earth sciences, environmental sciences, biological sciences, agricultural and veterinary sciences, information and computing sciences, engineering, technology, and the biomedical and clinical health sciences sub-grouping of medical and health science. The average citation rate (field-weighted) was calculated as a mean of the citation rates of these fields. Countries are ordered by average citation rate (field-weighted). Circle area indicates total number of STEM publications, 2002 to 2012. Green circles show countries above the average of the EU15 countries; yellow circles show countries above the normalised world average (1.0) but below the EU15 countries' average; red circles show those countries that are below the world average.

Source: InCites, Thomson Reuters (2012). Global Comparisons Dataset, 2002 to 2012. Report created 12 January 2014. Data processed 3 July 2013. Data from Web of Science.

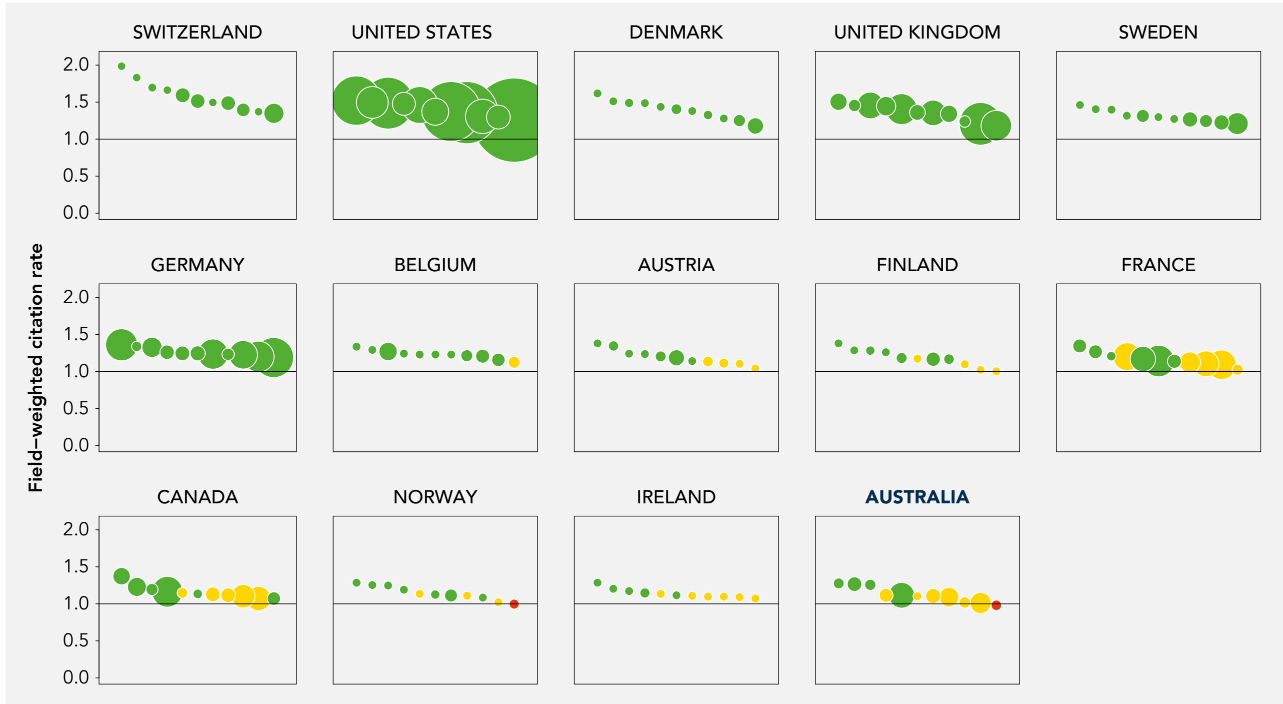
2.9 WHERE DOES AUSTRALIA DO WELL?

2.9.1 Australia compared with Europe and North America

There are four fields (for a list of fields see Appendix A) for which the Australian field-weighted citation rate is higher than the EU15 average (green circles)—earth sciences, physical sciences, mathematical sciences and the biomedical and clinical health sciences sub-group. Australia's performance in six fields is below the EU15 average, but above the world average (yellow circles)—agricultural and veterinary sciences, technology, chemical sciences, engineering, environmental sciences and biological sciences. One field, information and computing sciences, is below the world average (red circle) (see Figure 2-2 and Figure 2-3).

For Switzerland, the United States, Denmark, the United Kingdom, Sweden and Germany, all 11 fields considered have a higher than EU15 average citation rate (green circles) (Figure 2-2). The United States has the largest number of publications in almost all the fields measured. The United Kingdom, Germany and France all have a high number of publications.

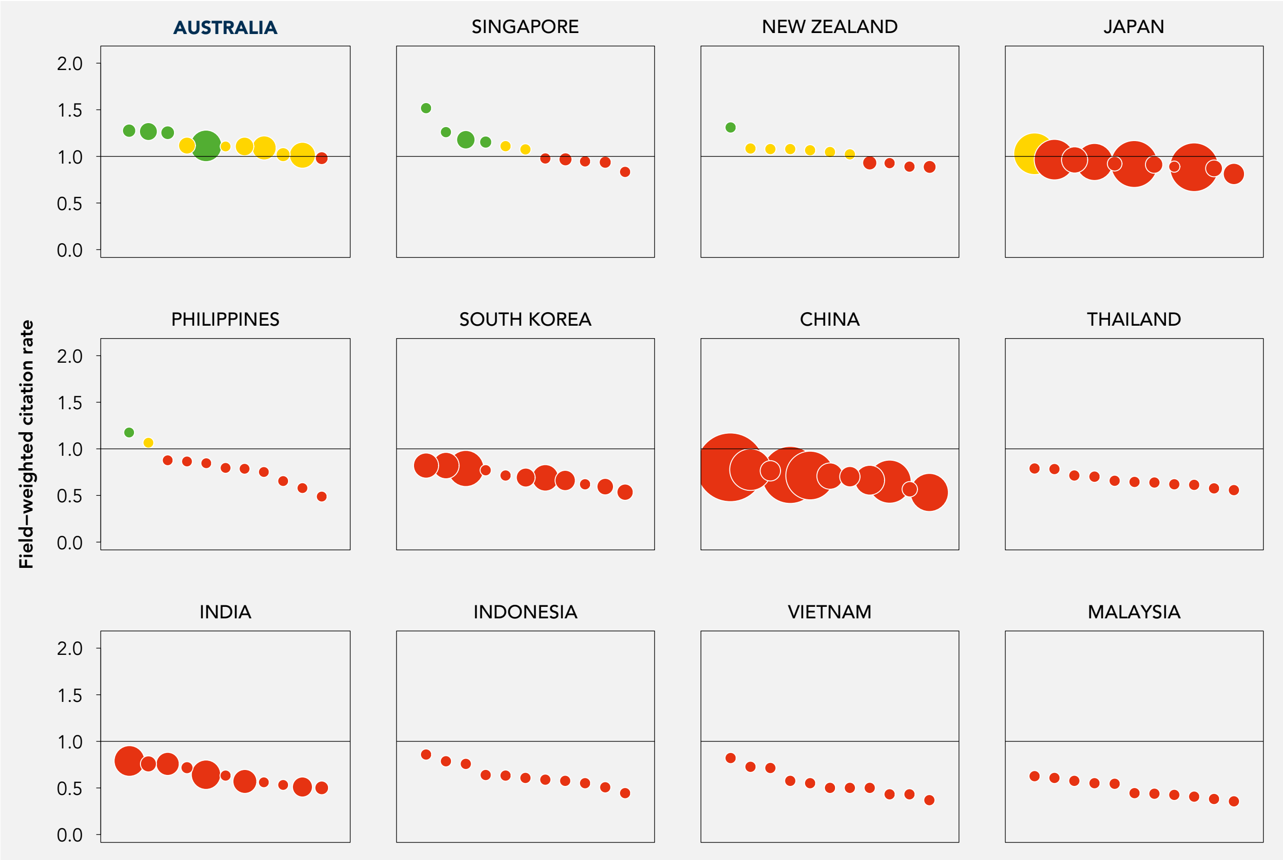
Figure 2-2 Australia's STEM research compared with that of selected countries in Europe and North America, by two-digit field, 2002 to 2012



Notes: Publication counts are Web of Science documents classified as article, note or review, by year of publication and assigned to a country based on the institutional address(es) listed in the publication. Each circle represents a STEM field (selected using Australia ERA 2012 FoR Level 1 categories mathematical sciences, physical sciences, chemical sciences, earth sciences, environmental sciences, biological sciences, agricultural and veterinary sciences, information and computing sciences, engineering, technology, and the biomedical and clinical health sciences sub-grouping of medical and health science) ordered by field-weighted citation rate. Circle area indicates total number of STEM publications, 2002 to 2012. The minimum circle size represents 12 550 publications. Fields with a publication number below this threshold over the period are represented by circles corresponding to this size to aid visualisation. Green circles show fields above the EU15 countries; yellow circles show fields above the world average (1.0) but below the EU15 countries; red circles show those fields that are below the world average.

Source: InCites, Thomson Reuters (2012). Global Comparisons Dataset, 2002 to 2012. Report created 12 January 2014. Data processed 3 July 2013. Data from Web of Science.

Figure 2-3 Australia's STEM research compared with that of New Zealand and selected Asian countries: by two-digit field, 2002 to 2012



Notes: Publication counts are Web of Science documents classified as article, note or review, by year of publication and assigned to a country based on the institutional address(es) listed in the publication. Each circle represents a STEM field (selected using Australia ERA 2012 FoR Level 1 categories mathematical sciences, physical sciences, chemical sciences, earth sciences, environmental sciences, biological sciences, agricultural and veterinary sciences, information and computing sciences, engineering, technology, and the biomedical and clinical health sciences sub-grouping of medical and health science) ordered by citation rate (field-weighted). Circle area indicates total number of STEM publications, 2002 to 2012. The minimum circle size represents 12 550 publications. Fields with publication number below this threshold over the period are represented by circles corresponding to this size to aid visualisation. Green circles show fields above the EU15 countries; yellow circles show fields above the normalised world average (1.0) but below the EU15 countries; red circles show those fields that are below the world average.

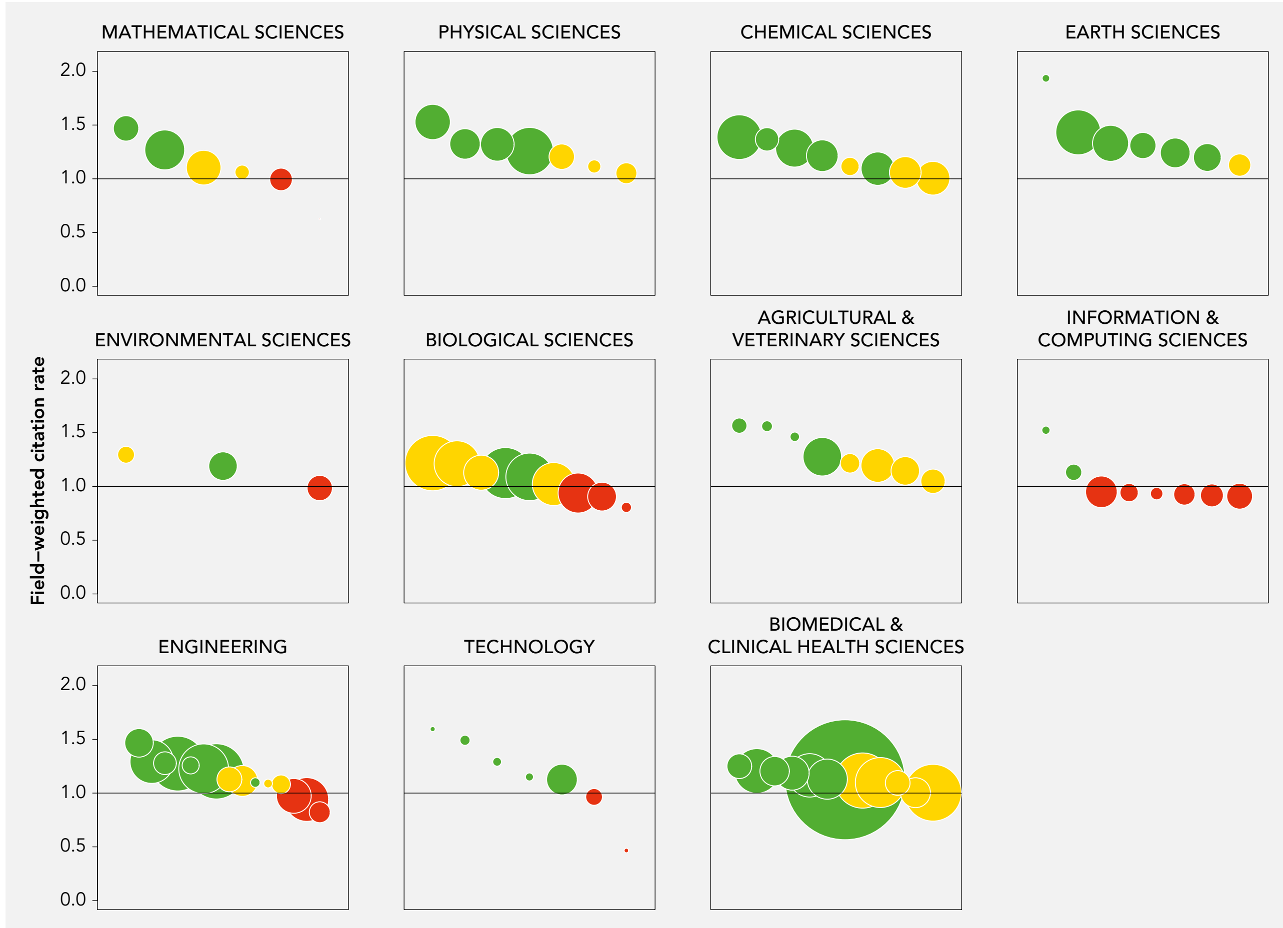
Source: InCites, Thomson Reuters (2012). Global Comparisons Dataset, 2002 to 2012. Report created 12 January 2014. Data processed 3 July 2013. Data from Web of Science.

2.9.2 Australia compared with other countries in our region

At an aggregate, national level, Australian STEM publications have higher citation rates than those from other countries in our region (see Figure 2-3). Singapore has a higher citation rate than the EU15 average in four fields (agriculture, mathematics, engineering and chemical sciences). Both New Zealand and the Philippines have a higher rate than the EU15 average in technology.

In terms of total output, China produces the greatest number of publications; it is followed by Japan, India and South Korea. Japan has one field, chemical sciences, with a citation rate above the world average.

Figure 2-4 Australian STEM research, by four-digit sub-field, 2002 to 2012



Notes: Publication counts are Web of Science documents classified as article, note or review, by year of publication and assigned to a country based on the institutional address(es) listed in the publication. Each circle represents a STEM subject group (selected using Australia ERA 2012 FoR Level 2 categories) ordered by field-weighted citation rate. Circle area indicates total number of STEM publications, 2002 to 2012. Green circles show sub-fields above the EU15 countries; yellow circles show sub-fields above the world average (1.0) but below the EU15 countries; red circles show those sub-fields that are below the world average.

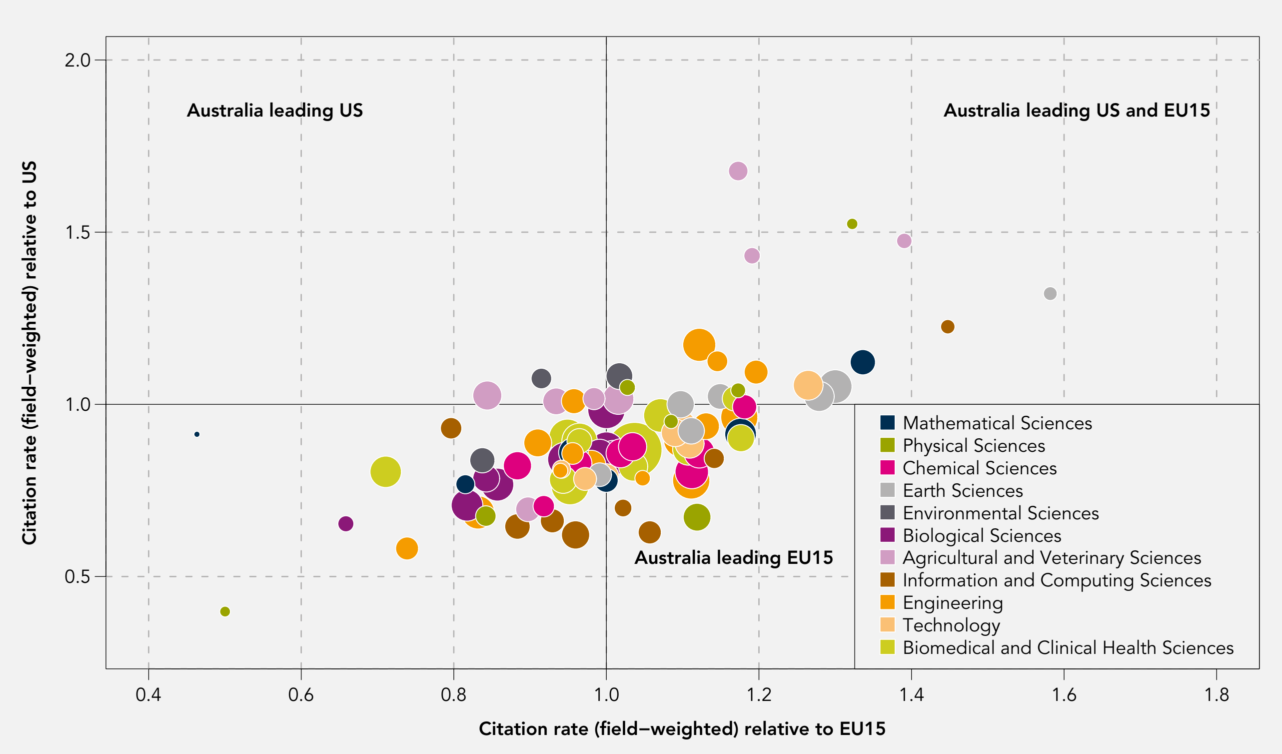
Source: InCites, Thomson Reuters (2012). Global Comparisons Dataset, 2002 to 2012. Report created 30 January 2014. Data processed 3 July 2013. Data from Web of Science.

2.9.3 Australian STEM research in sub-fields

Australia ranks above the EU15 in several sub-fields, particularly in the fields of engineering, physical sciences, chemical sciences, earth sciences, mathematical sciences and agricultural and veterinary sciences (see Figure 2-4).

The largest number of publications comes from the biomedical and clinical health sciences sub-group of clinical sciences; it accounted for 12.4 per cent of total Australian STEM publications in 2002 to 2012.

Figure 2-5 Citation rates for Australian STEM publications compared with those for the United States and the EU15, 2002 to 2012



Notes: Publication counts are Web of Science documents classified as article, note or review, by year of publication and assigned to a country based on the institutional address(es) listed in the publication. Each circle represents a STEM subject group (selected using Australia ERA 2012 FoR Level 2 categories) ordered by citation rate (field-weighted). Circle area indicates total publications, 2002 to 2012. Values greater than one show Australia's field-weighted citation rate is greater than the corresponding United States or EU15 value. The top left quadrant shows where the Australian citation rate is higher than that for the United States. The bottom right quadrant shows where the Australian citation rate is higher than that for the EU15. The top right quadrant shows where the Australian rate is higher than for both the United States and the EU15. The bottom left shows subfields for which the Australian rate is below those for both the United States and the EU15.

Source: InCites, Thomson Reuters (2012). Global Comparisons Dataset, 2002 to 2012. Report created 30 January 2014. Data processed 3 July 2013. Data from Web of Science.

2.10 WORLD-LEADING AUSTRALIAN SUB-FIELDS

Citation rates for Australian STEM publications in 20 sub-fields from a total of 91 are above those for the United States and the EU15 (see Figure 2-5, top right); rates for five sub-fields are above those for the United States but not the EU15 (top left); rates for 27 sub-fields are above those for the EU15 but below those for the United States (lower right). Table 2-3 shows a breakdown of these sub-fields. In addition, rates for 39 sub-fields are lower than in both the United States and the EU15 (lower left).

Engineering, geology and agriculture are areas in which Australia leads both the EU15 and the United States based on high field-weighted citation rates.

Table 2-3 STEM sub-fields for which Australian citation rates are higher than those for the United States and/or the EU15

Sub-field	Total publications (2002 to 2012)	Australian share of field (%)
Higher than United States and EU15		
Geology	6584	5.6
Civil engineering	6190	4.1
Veterinary sciences	4845	4.0
Geochemistry	4247	6.3
Atomic, molecular, nuclear, particle and plasma physics	4078	1.8
Environmental science and management	2652	6.3
Atmospheric sciences	2234	3.5
Statistics	2113	3.6
Medical biochemistry and metabolomics	1999	2.4
Interdisciplinary engineering	1687	2.2
Aerospace engineering	951	2.3
Horticultural production	757	4.0
Agriculture, land and farm management	378	3.5
Agricultural biotechnology	334	3.5
Other agricultural and veterinary sciences	292	6.4
Industrial biotechnology	252	1.6
Data format	221	3.6
Other earth sciences	188	7.3
Other engineering	168	3.7
Environmental biotechnology	85	1.4
Higher than EU15		
Clinical sciences	47018	3.7
Electrical and electronic engineering	9975	2.3
Mechanical engineering	9789	2.7
Materials engineering	8091	2.0
Ecology	7378	7.6
Astronomical and space sciences	7322	4.1
Cardiovascular medicine and haematology	6516	2.9
Physical chemistry (incl. Structural)	6508	2.1
Immunology	5261	3.7
Applied mathematics	5197	2.2
Organic chemistry	4698	1.9
Medical microbiology	3761	3.2
Optical physics	3688	2.5
Other chemical sciences	3634	2.3
Inorganic chemistry	3277	1.9
Communications technologies	3082	2.7

Sub-field	Total publications (2002 to 2012)	Australian share of field (%)
Condensed matter physics	3036	1.6
Physical geography and environmental geoscience	2890	4.8
Ophthalmology and optometry	2827	4.3
Resources engineering and extractive metallurgy	2660	3.1
Geophysics	2519	4.7
Macromolecular and materials chemistry	1781	1.6
Distributed computing	1486	3.2
Computer software	864	3.4
Other information and computing sciences	505	3.4
Maritime engineering	298	4.2
Medical biotechnology	211	2.9
Higher than United States		
Crop and pasture production	3684	4.2
Fisheries sciences	2653	5.8
Environmental engineering	2021	4.1
Forestry sciences	1237	4.5
Soil sciences	925	4.1

2.11 CONCLUDING REMARKS

The findings presented here extend and support those reported in previous analyses of Australia's research performance (West 2013). On the basis of the field-weighted citation rates for STEM publications, Australia's overall research performance could be improved when compared with the other countries examined.

This overall performance means we have no room for complacency. Nor can we let STEM drift. We must distribute resources carefully and strategically—just like most other countries.

CHAPTER 3

3. HIGHLY CITED RESEARCH

This chapter analyses Australia's STEM publications that are amongst the top 1 per cent of cited publications globally—an indicator of the most influential Australian STEM publications.

3.1 MAIN FINDINGS

- In the broad group of natural and physical sciences, Australia has a lower proportion of the top 1 per cent of cited publications than Canada, France, China, Germany, the United Kingdom and the United States, but a higher proportion than eight of the European countries assessed.
- Australian research in all STEM fields is represented in the top 1 per cent of cited publications globally, the largest number being in the fields of medicine and engineering.

3.2 DATA SOURCES AND TERMINOLOGY

Data for all fields that are consistent with those used for previous analyses in Chapter 2 are not available, so the top 1 per cent of publications in the area of natural science and engineering are used as a broad indication of STEM. In addition, presented here are data on highly cited STEM fields from the Scopus database.

3.3 COUNTRIES ANALYSED

This chapter provides an analysis of the 11 European nations (Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Norway, Sweden, Switzerland and the United Kingdom) and comparator nations from our region (New Zealand, China, India, Indonesia, Japan, Malaysia, the Philippines, Singapore, South Korea, Thailand and Vietnam).

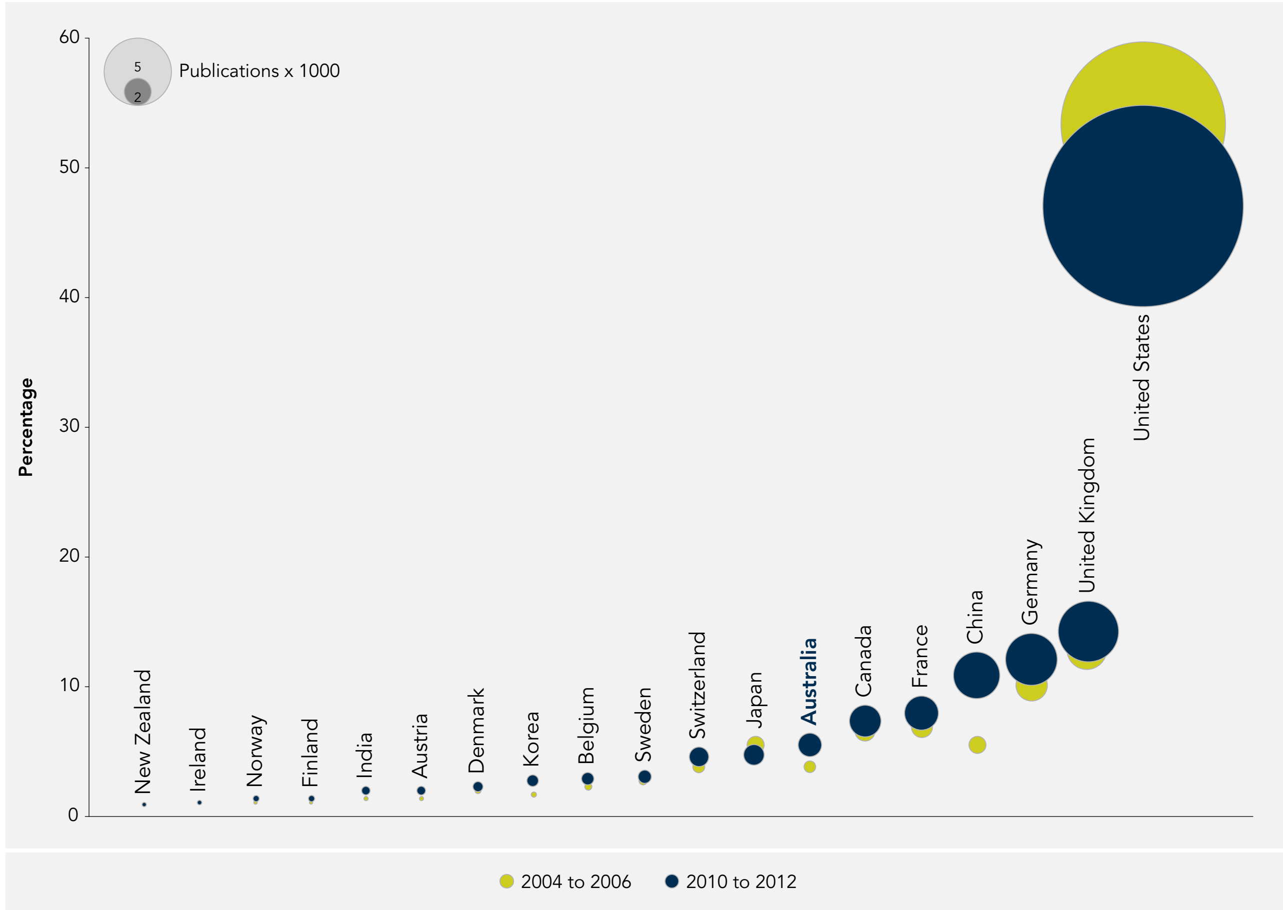
3.4 AUSTRALIA'S SHARE OF THE MOST CITED STEM PUBLICATIONS GLOBALLY

Australia has a higher proportion of the top 1 per cent of cited publications in natural science and engineering than eight of the European comparator countries, and both the absolute number and the share of the top 1 per cent of cited publications have increased since the baseline period of 2004 to 2006 (see Figure 3-1).

By contrast, Australia has a lower proportion of the top 1 per cent of cited publications in natural science and engineering than Canada, France, China, Germany, the United Kingdom and the United States. The United States continues to have the largest share, but the proportion of the top 1 per cent it has produced has decreased since 2004 to 2006, reflecting an increase in the publication output of countries such as China, Germany and the United Kingdom.

The increase in the absolute number of publications in the top 1 per cent is a consequence of the increase in publication numbers globally over time.

Figure 3-1 Share of the top 1 per cent of citations in natural science and engineering, 2004 to 2006 and 2010 to 2012



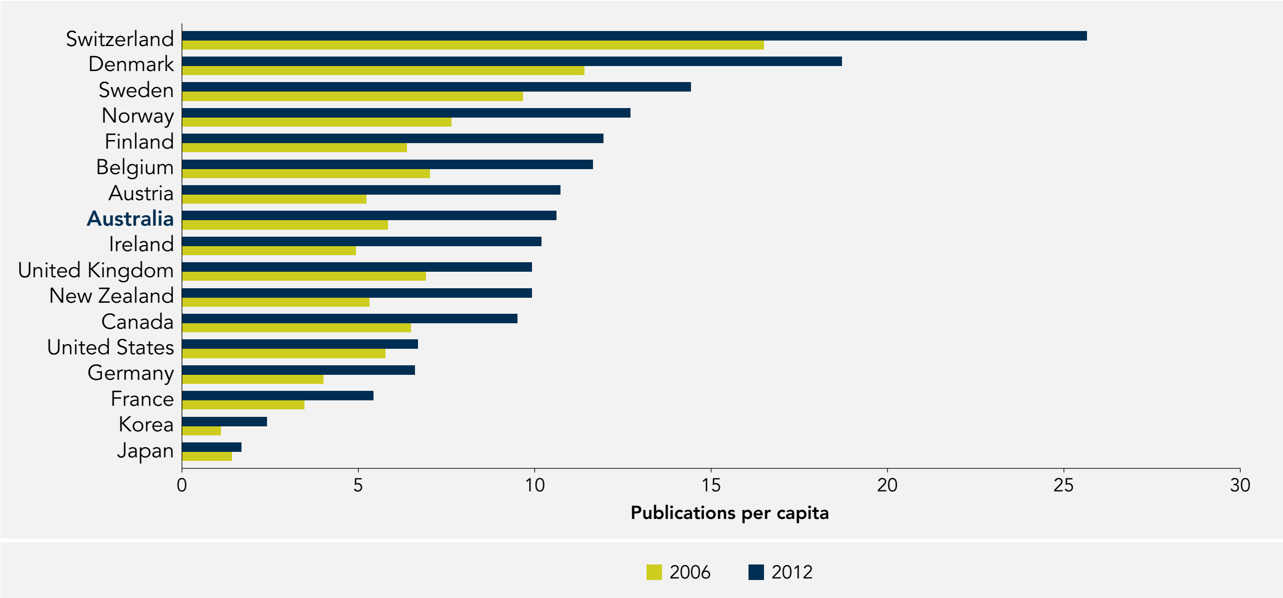
Notes: Yellow circles show the share of the world's top 1 per cent of highly cited publications in natural sciences and engineering for each country for the period 2004 to 2006. This takes the top 1 per cent of publications based on citation in the natural sciences and engineering classification and attributes them to country of origin based on address field across two points of time. Blue circles show the same information for the period 2010 to 2012. Circle diameter represents the number of publications issued during the period. Countries are ordered horizontally by increasing citation rate; horizontal placement is to help with visualisation.

Source: Department of Industry special data request from Thomson Reuters (2012).

The scale of research endeavour and the productivity of researchers are important factors determining countries' research performance. To provide further insights into how countries compare in their share of 'world-leading' publications, the proportions of top 1 per cent of publications are normalised against the country's population and then shown relative to each country's share of researchers in the national workforce and national R&D expenditure.

When top publications are normalised to each country's population, Australia has fewer publications in the top 1 per cent by citation than Switzerland, Denmark, Sweden, Finland, Norway, Belgium and Austria (see Figure 3-2). It is worth noting that nations have different proportions of researchers in business and higher education and that the number of researchers would vary between fields.

Figure 3-2 Per capita contribution to top 1 per cent of citations in natural science and engineering publications



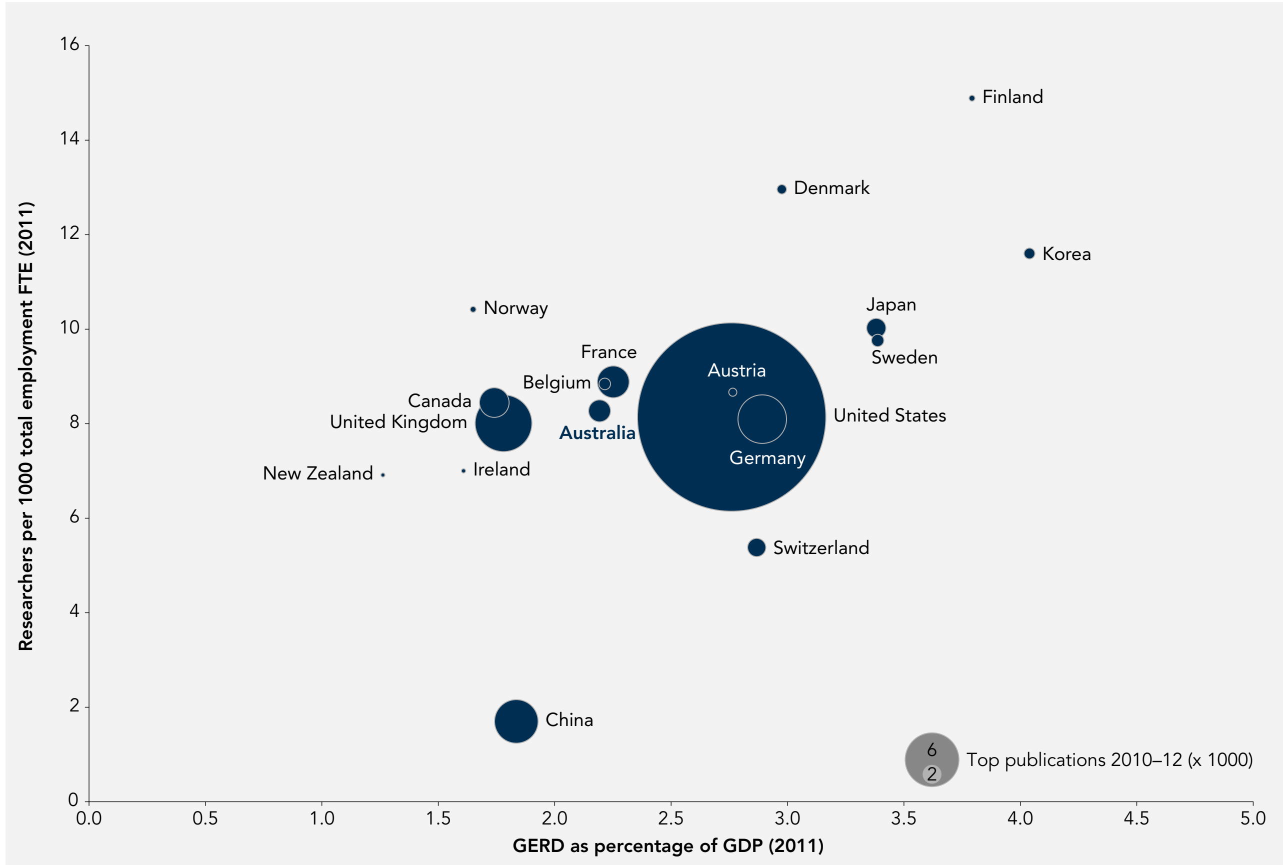
Source: Department of Industry special data request from Thomson Reuters (2012); OECD Main Science and Technology Indicators, January 2014.

The population of a country provides a crude measure of that country's research capacity. Figure 3-3 shows the number of publications in the top 1 per cent (indicated by circle size) for each comparator country, the number of researchers per 1000 in employment and gross expenditure on R&D, or GERD, as a share of gross domestic product. The caution here is that not all researchers in a country will have the goal of publishing in citable journals; for example, Denmark has approximately 60 per cent of researchers in business, whereas Australia has just over 30 per cent (see Chapter 7). The proportions of researchers in higher education relative to business will have an impact on the nature of the output from research.

Australia is mid-range among the comparator countries both for the number of researchers per 1000 and for GERD as a share of GDP.

There is an increasing number of researchers per year for most of the countries assessed (data not shown). The most recent data for Australia are from 2008, so assessing Australia's recent position will depend on the availability of new data.

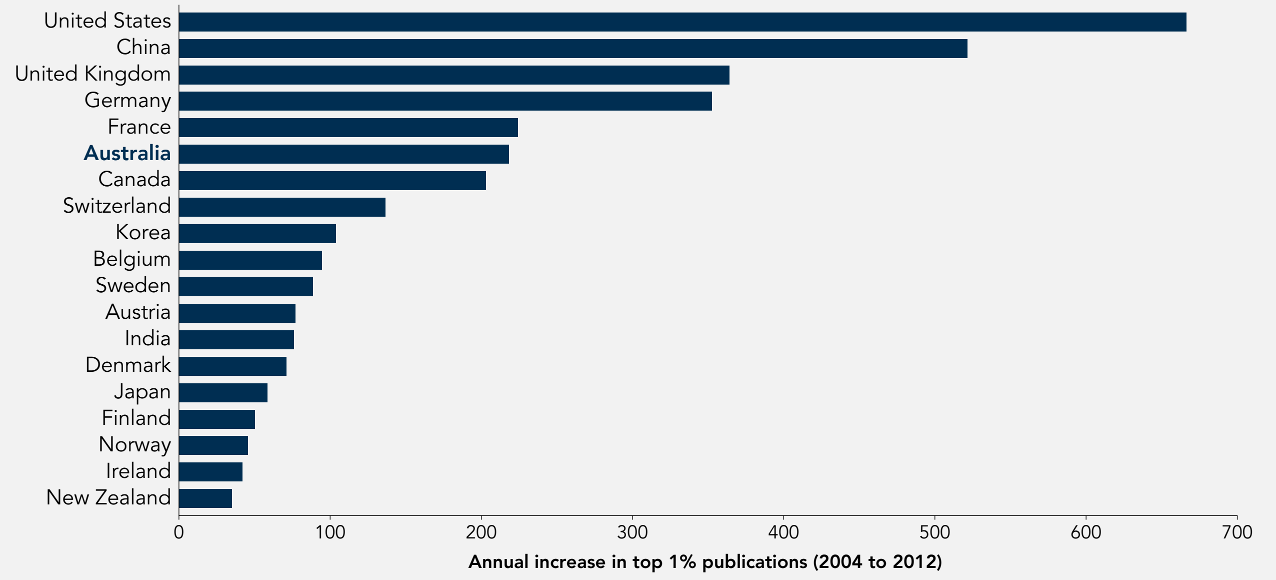
Figure 3-3 Top natural science and engineering publications (2010 to 2012) by researchers per 1000 total employment and GERD as share of GDP (2011)



Notes: Circle diameter represents the number of top 1 per cent of highly cited publications in natural sciences and engineering for each country in 2010 to 2012. This takes the top 1 per cent of publications based on citation in the natural sciences and engineering classification and attributes them to country of origin based on address field. The scale shows the volume of publications in thousands for each country. The latest available data on researchers per 1000 total employment and GERD as a share of GDP for Switzerland were both 2008 and for Australia were 2008 and 2010 respectively.

Source: Department of Industry special data request from Thomson Reuters (2012); OECD Main Science and Technology Indicators, January 2014.

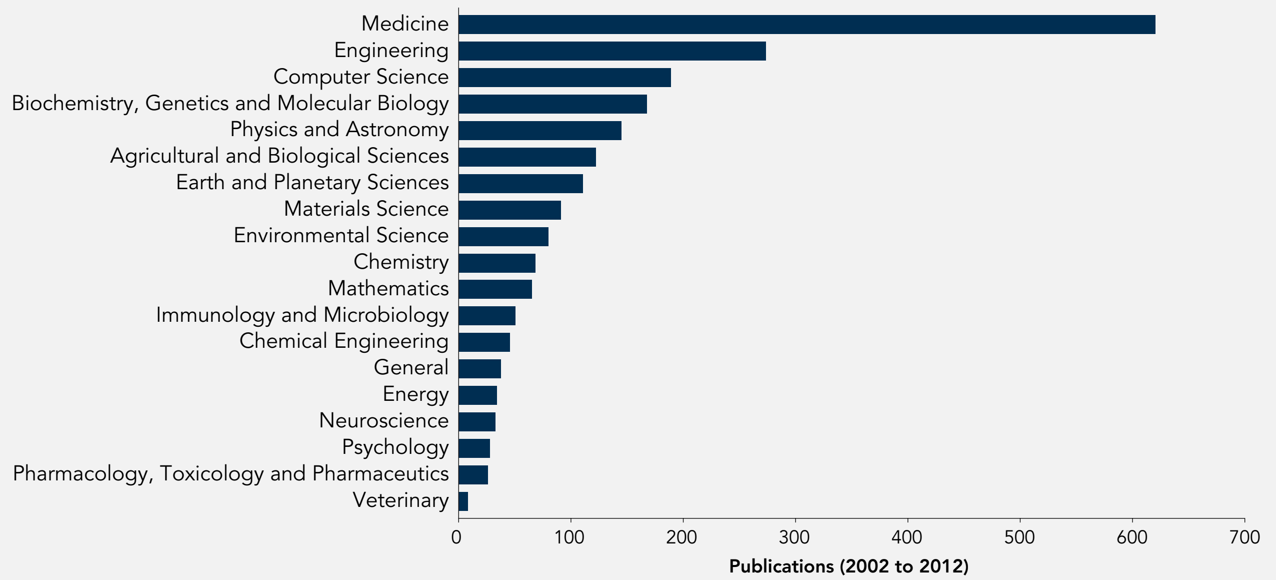
Figure 3-4 Annual increase in number of natural science and engineering publications: top 1 per cent of cited publications, by country and citation rate, 2004 to 2012



Notes: The increase in the number of top publications per year was calculated by a linear fit to data from 2004 to 2012 grouped into three-year intervals.

Source: Department of Industry special data request from Thomson Reuters (2012); OECD Main Science and Technology Indicators, January 2014.

Figure 3-5 Australian publications contributing to the top 1 per cent of global STEM publications, by STEM field and citation rate, 2002 to 2012



Source: Research carried out by Coombs Policy Forum at the Australian National University (2014). Data sourced from Scopus using STEM field codes with the top 1 per cent of publications based on citation rate and normalised by the expectation value of citations in the field for each year. The mean of the annual normalised citation rates is shown.

3.5 THE INCREASE IN THE NUMBER OF HIGHLY CITED PUBLICATIONS EACH YEAR

Figure 3-4 shows the increase in the number of top 1 per cent cited publications each country is producing in natural sciences and engineering. Australia produces more top 1 per cent cited publications than many of the European and Asian countries analysed, with an average annual increase of 219 publications between 2004 and 2012. This average is, however, below that for France, Germany, the United Kingdom, China and the United States.

The global pool of top research publications is increasing, and Australia is producing an increasing number of most cited publications each year. This contrasts with Australia's overall mid-range performance among the comparator countries in STEM and its sub-fields (see Figure 2-1 to Figure 2-5).

3.6 AUSTRALIAN STEM PUBLICATIONS IN THE TOP 1 PER CENT BY FIELD

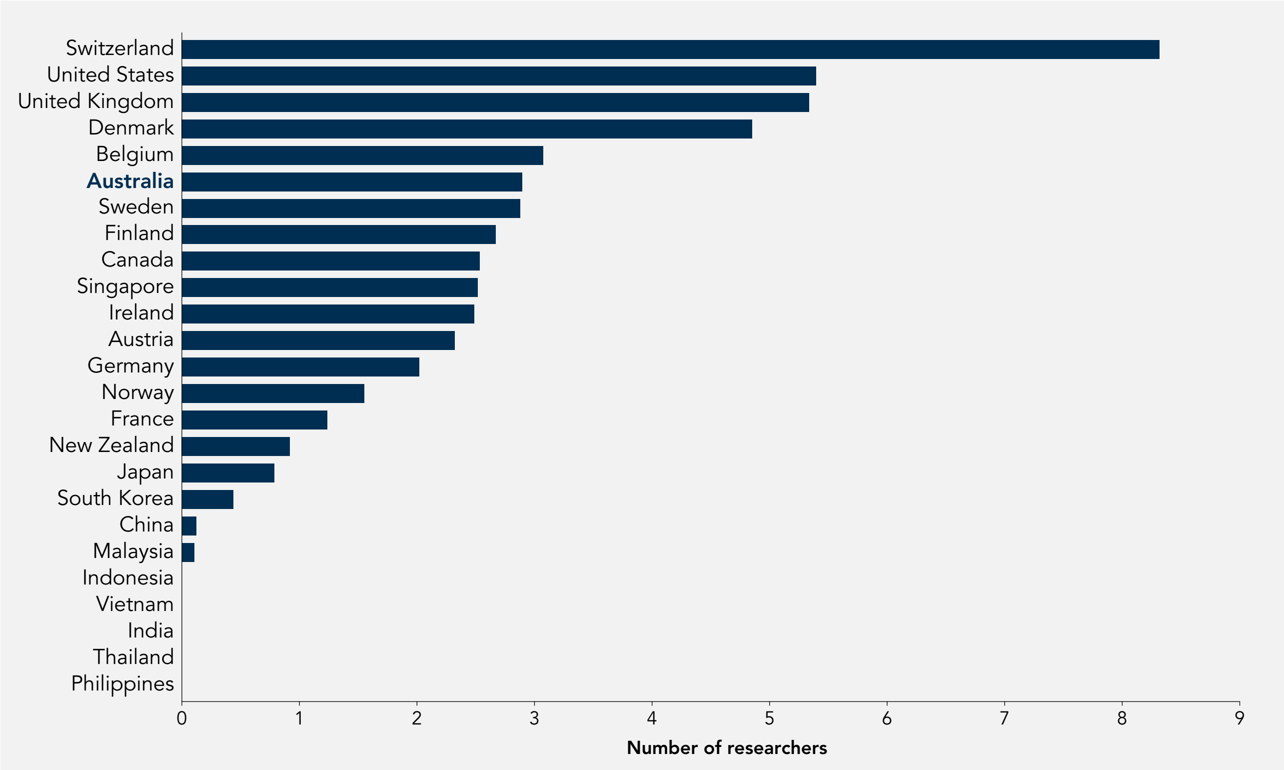
Between 2002 and 2012 Australia produced 7949 STEM publications that were cited in the top 1 per cent of STEM publications globally (see Figure 3-5 and Table 3-1). The largest single field was medicine, with 3111 publications; this was followed by engineering, with 1371 publications. Every field is represented in the top 1 per cent of cited STEM publications with attributions to Australian researchers.

Table 3-1 STEM fields in Australian publications that contribute to the top 1 per cent of global STEM publications, by citation rate, 2002 to 2012

Field of research	Australian share of top 1 per cent of each field (%)
Earth and Planetary Sciences	8.9
Agricultural and Biological Sciences	7.9
Environmental Science	7.3
Veterinary	6.7
Medicine	5.6
Immunology and Microbiology	5.1
General	5.0
Neuroscience	4.5
Psychology	4.3
Biochemistry, Genetics and Molecular Biology	4.0
Energy	3.8
Computer Science	3.2
Physics and Astronomy	3.2
Mathematics	3.1
Pharmacology, Toxicology and Pharmaceutics	3.1
Chemical Engineering	3.1
Engineering	3.0
Materials Science	2.9
Chemistry	2.5

Source: Research carried out by Coombs Policy Forum at the Australian National University (2014). Data sourced from Scopus using STEM field codes with the top 1 per cent of publications based on citation rate and normalised by the expectation value of citations in the field for each year. The mean of the annual normalised citation rates is shown.

Figure 3-6 Top cited researchers per million population, selected countries, 2014



Source: Data obtained from Thomson Reuters 2014 Highly Cited Researchers List (Thomson Reuters 2014). To be included in the list a researcher must feature in the top 1 per cent by total citation in their field (by the Thomson Reuters Essential Science Indicators) from 2002 to 2012. The number of researchers included from each field is based on the square root of the number of authors featured in each field. Highly cited researchers by address of primary affiliation: *CIA The World Factbook (2014)*, Country Comparison: population, July 2014.

3.7 HIGHLY CITED AUSTRALIAN RESEARCHERS

Australia has 2.9 top cited researchers per million population; this places us below Switzerland, the United States, the United Kingdom, Denmark and Belgium (see Figure 3-6).

3.8 CONCLUDING REMARKS

When our research performance is compared with that of 11 Western European countries, the United States and Canada, it is clear that our best are among the best in the world.

While research in all STEM fields contributes to our share of the world's top 1 per cent of cited publications, research in medicine and engineering plays a dominant part.

CHAPTER 4

4. PATENTS

This chapter examines the number of Patent Cooperation Treaty patent applications and triadic patent families filed by Australian inventors compared with inventors from other countries.

4.1 MAIN FINDINGS

- The number of Patent Cooperation Treaty applications and triadic patent families filed by an Australian inventor has fallen steadily in recent years. PCT applications have fallen by 22 per cent from their peak in 2005; triadic applications have fallen by 45 per cent from their peak in 2000.
- The number of PCT applications and triadic patents has increased for all the comparator countries other than the United Kingdom.
- The number of Australian PCT applications with a foreign co-inventor increased between 2002 and 2011. Despite this, the proportion of Australian PCT patents filed with an international co-inventor in 2011 was lower than that for most of the comparator countries, including all the European countries.

4.2 BACKGROUND

Patent systems have an important role in stimulating technological innovation by providing legal protection for intellectual property and disseminating useful technical information (Merrill et al. 2004). This facilitates technology transfer and the commercialisation and diffusion of knowledge. The patent system has clear economic objectives, but it also leads to non-economic benefits by increasing innovation and opening up access to new technologies (Advisory Council on Intellectual Property 2011).

Patents can demonstrate a country's capacity or willingness to exploit knowledge and translate it into potential economic benefits (European Commission 2012). They have been used to track knowledge diffusion across countries, regions, technologies and companies and to assess the international reach of innovative activities (Dernis 2007). Patent counts have been described as 'measuring something above and beyond R&D inputs, a creation of an underlying knowledge stock' (Hall et al. 1986).

4.3 TERMINOLOGY

Like many countries, Australia issues national patents through a national patent office, thereby protecting inventions developed within national boundaries. Local patents represent only a small proportion of total Australian patents, however: a better benchmark for innovation with international ramifications is a comparison of applications under the PCT and triadic patent families.

For the purposes of this report, the nationality of a patent is considered to be the inventor's country of residence.

4.3.1 The Patent Cooperation Treaty

Australian patents provide protection within Australia. To obtain protection in other countries inventors can either file separately in individual countries or file a single international application under the Patent Cooperation Treaty, which is administered by the World Intellectual Property Organization. A patent registered under the PCT is the closest thing to an international patent and protects inventions in over 180 countries.

Both applicants and patent offices in PCT member states benefit from the uniform formality requirements, the international search and preliminary examination reports, and the centralised international publication provided by the PCT system (World Intellectual Property Organization 2010).

4.3.2 Triadic patent families

Another measure of international innovation is the triadic patent family—a set of patents protecting the same invention and filed at the European Patent Office, the Japanese Patent Office and the US Patent and Trademark Office. It has been suggested that triadic patent families provide an improved measure of innovative performance and technological change at the international level (Dernis 2003). This is because triadic patent families cover a single invention and the resultant indicators are less influenced by individual patent offices' rules and regulations and patenting strategies (Dernis 2007).

4.4 DATA SOURCES

The OECD Patent Database, created by the Directorate for Science, Technology and Industry, covers patents filed under the PCT, and counts are based on data received from the European Patent Office. Only the original application is counted, thus avoiding double-counting of the same invention. The EPO Database provides good coverage for both OECD member and non-OECD member economies from 1981. PCT applications are presented according to the region of the inventor's residence and the priority year.[1]

The OECD Patent Database also covers triadic patent families. Data on triadic patent families are mainly derived from the EPO's Worldwide Statistical Patent Database (PATSTAT).

4.5 COUNTRIES ANALYSED

As in the previous chapter, two groups of benchmarking nations were identified for analysis—countries at stages of development similar to that of Australia and with similar governance systems (the United States, Canada and selected European nations), and selected countries in the Asia–Pacific region.

This chapter compares Australia with the 11 European comparator countries (Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Norway, Sweden, Switzerland and the United Kingdom), North America (Canada and the United States), and countries in our region (China, Japan, New Zealand, South Korea and Singapore).

4.6 PATENT APPLICATIONS IN AUSTRALIA AND ELSEWHERE

4.6.1 Australian patent applications, 1981 to 2011

In 2012, 26 358 'standard patents' were filed in Australia—10 per cent by Australian residents and 90 per cent by foreign applicants (IP Australia 2013). PCT applications accounted for 72 per cent (19 107) of the total. US residents filed the highest number of Australian standard patents (11 376), followed by Japan (1746) and Germany (1594).

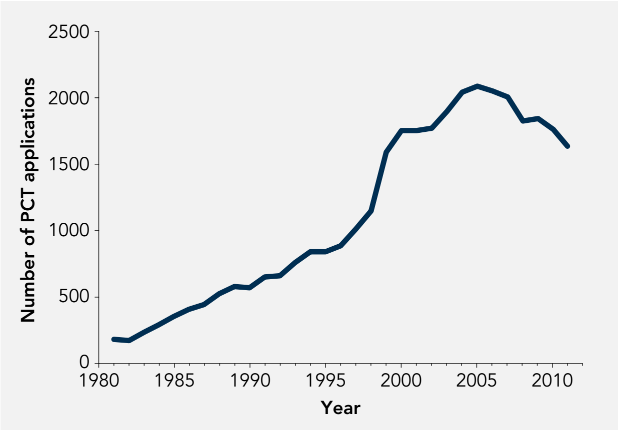
The number of PCT patent applications by an Australian inventor increased from 172 in 1981 to a peak of 2092 in 2005 (see Figure 4-1). The most rapid growth was between 1996 and 2005; this was followed by a 22 per cent decline from 2005 to 2011.

Triadic patent families form a much smaller group than PCT patents (see Figure 4-2). In 1985 there were 153 triadic patents with an Australian inventor, compared with 357 PCT patents. By 2000 the number of triadic patents had increased to 380 (a 148 per cent increase) and PCT patents to 1755 (362 per cent). After 2000 triadic patent families began to decline (by 45 per cent from 2000 to 2011), whereas PCT applications continued to rise until 2005.

The decline in PCT applications after 2007 might in part be a reaction to the global financial crisis. The Department of Industry reported an 11.6 per cent decrease in Australian standard patent applications (that is, applications filed in Australia) from 2007 to 2009. It attributed this to economic disruption caused by the GFC (DIISR 2012). By contrast, the decline in triadic patents started in 2001, six years before the GFC began.

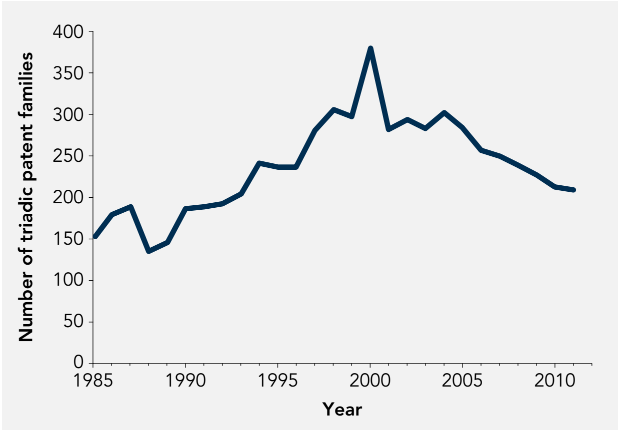
1 The priority year, the year of the first international filing of a patent, is used as a reference date.

Figure 4-1 Patent applications with an Australian inventor filed under the Patent Cooperation Treaty, 1981 to 2011



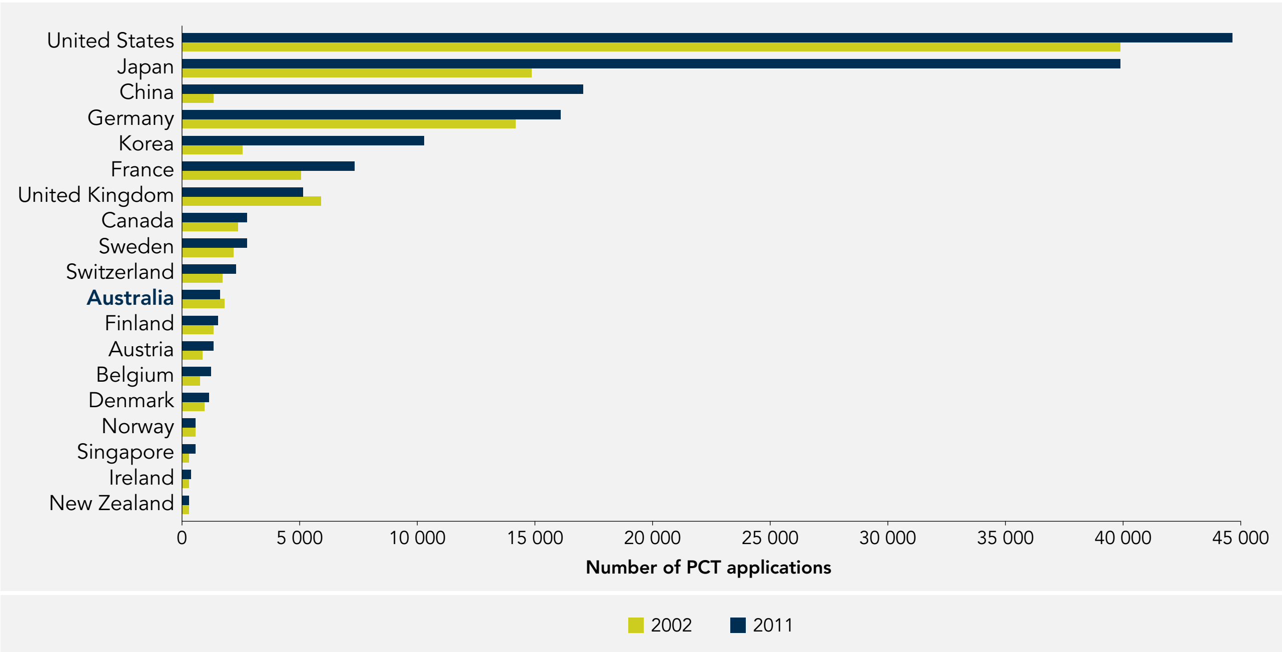
Source: OECD Main Science and Technology Indicators, January 2014.

Figure 4-2 Triadic patent family applications with an Australian inventor, 1985 to 2011



Source: OECD Main Science and Technology Indicators, January 2014.

Figure 4-3 Patent applications filed under the Patent Cooperation Treaty, selected countries, 2002 and 2011



Source: OECD Main Science and Technology Indicators, January 2014.

4.6.2 Australia's patent applications and those of comparator countries, 2002 to 2011

With the exception of the United Kingdom and New Zealand, the number of PCT applications filed by each of the comparator countries increased between 2002 and 2011 (see Figure 4-3 and Table 4-1). Australian applications declined by 7 per cent, compared with increases of between 10 and 50 per cent in many of the European comparator countries. Australia's rank within the comparator countries decreased from ninth in 2002 to eleventh in 2011, with Switzerland and China overtaking Australia.

The United States had the greatest number of PCT applications in both 2002 and 2011. By 2011, however, the gap between the United States and its nearest competitor, Japan, had decreased. China's PCT applications grew by 1194 per cent between 2002 and 2011, from 1316 to 17 027. Of the Asia–Pacific countries analysed, PCT patent activity in China was well behind that of Japan but ahead of Korea, Australia, Singapore and New Zealand. Asian nations have led the growth in patent applications, with China, Korea, Japan and Singapore increasing the most.

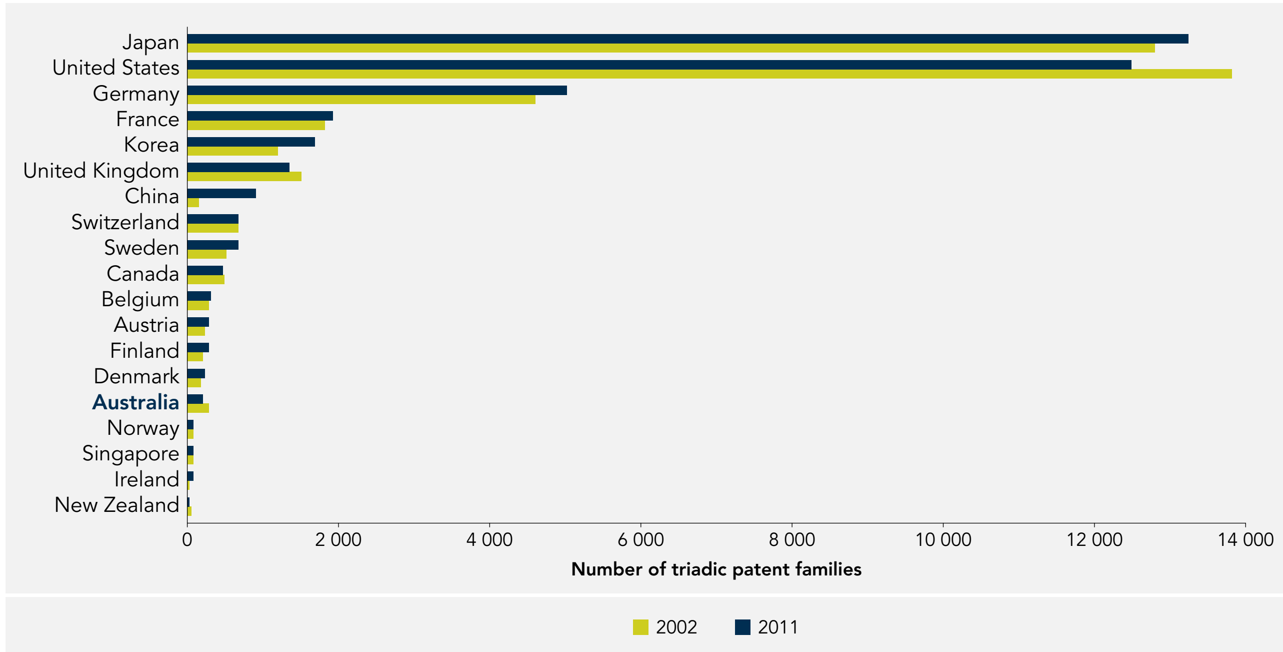
The number of Australian triadic patent families declined by 29 per cent between 2002 and 2011, from 294 to 209. Among the 19 countries analysed in this chapter, Australia had the fifth lowest number of triadic patent families in 2011 (see Figure 4-4).

Table 4-1 International growth in Patent Cooperation Treaty applications, 2002 to 2011

Country	2002 (no.)	2011 (no.)	Change (%)
China	1 316	17 027	1 194
Korea	2 591	10 237	295
Japan	14 890	39 869	168
Singapore	309	582	88
Belgium	801	1 191	49
Ireland	257	382	48
Austria	865	1 284	48
France	5 082	7 334	44
Switzerland	1 679	2 294	37
Sweden	2 219	2 715	22
Denmark	984	1 178	20
Canada	2 367	2 765	17
Finland	1 311	1 495	14
Germany	14 150	16 055	13
United States	39 907	44 598	12
Norway	575	594	3
Australia	1 768	1 640	–7
New Zealand	313	282	–10
United Kingdom	5 941	5 176	–13

Source: OECD Main Science and Technology Indicators, January 2014.

Figure 4-4 Triadic patent families, by country, 2002 and 2011



Source: OECD Main Science and Technology Indicators, January 2014.

4.6.3 PCT applications in Australia and comparator countries after the global financial crisis

After the global financial crisis global PCT applications fell by 4.5 per cent in 2009 (World Intellectual Property Organization 2010), the first such decrease in three decades (Mara 2010). In some ways the GFC rearranged the international patent landscape, resulting in large decreases in applications in many Western nations but growth in many Asian countries. China, in particular, experienced a large increase in PCT applications between 2008 and 2009, at 29.7 per cent (see Table 4-2).

The countries that experienced the greatest decrease in PCT applications immediately following the GFC were Ireland (–11 per cent), Denmark (–10 per cent), the United Kingdom (–6 per cent), Sweden (–5 per cent) and the United States (–4 per cent). Although Australia's PCT applications increased by 1 per cent between 2008 and 2009, the number declined again in 2010 and 2011, continuing the fall from the 2005 peak (see Figure 4-1).

Table 4-2 International PCT applications, 2008 and 2009

Country	2008 (no.)	2009 (no.)	Change (%)
China	6 913	10 682	55
Korea	7 156	8 690	21
Japan	25 429	28 824	13
Norway	666	749	12
Austria	1 189	1 278	8
Belgium	1 087	1 142	5
Canada	2 614	2 689	3
Germany	17 029	17 287	2
France	6 898	7 009	2
Australia	1 830	1 846	1
Finland	1 502	1 502	0
Switzerland	2 254	2 220	–1
United States	44 546	42 799	–4
New Zealand	337	324	–4
Sweden	3 000	2 847	–5
United Kingdom	6 020	5 680	–6
Singapore	649	606	–7
Denmark	1 252	1 127	–10
Ireland	427	378	–11

Source: OECD Main Science and Technology Indicators, January 2014.

The overall patenting trend for Australia before and after the GFC was one of declining PCT and triadic patent activity. This contrasts with most of the European countries analysed: all but the United Kingdom achieved overall growth in PCT patent applications from 2002 to 2011, despite a general slowdown in the post-GFC years.

4.6.4 International collaboration in PCT patents, 2002 and 2011

Globalisation trends are reflected in the internationalisation of R&D and innovative activities (Guellec & Potterie 2001). Cross-border co-invention represents international collaboration in the inventive process (Dernis 2007).

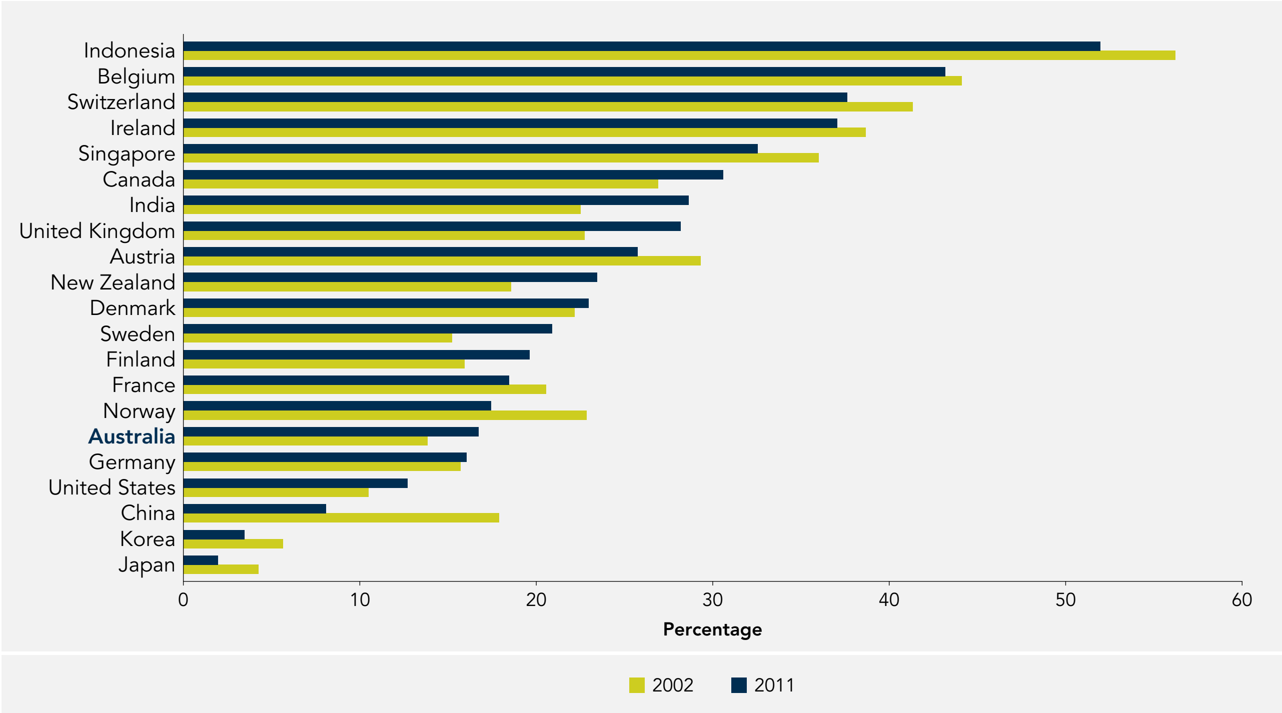
In 2011 the share of Australian PCT patent applications filed with a co-inventor located abroad was 17 per cent (see Figure 4-5). Cross-border co-invention was lower in Australia than in all the analysed European countries, New Zealand (23 per cent), India (29 per cent), Canada (31 per cent), Singapore (33 per cent) and Indonesia (52 per cent). Australia's cross-border co-invention did, however, increase from 14 per cent in 2002 to 17 per cent in 2011.

4.7 COLLABORATION BETWEEN BUSINESS AND RESEARCH INSTITUTIONS ON INNOVATION

Australia's low patenting rates reflects the poor collaboration between business and research in the public sector (Figure 4-6). Australia has the lowest level of business to research collaboration among the comparator countries. In OECD analysis of innovation active businesses, out of a total of 33 countries, Australia ranks 32nd on business to research collaboration for small to medium enterprises (SMEs), and 33rd for large firms (OECD 2011b).

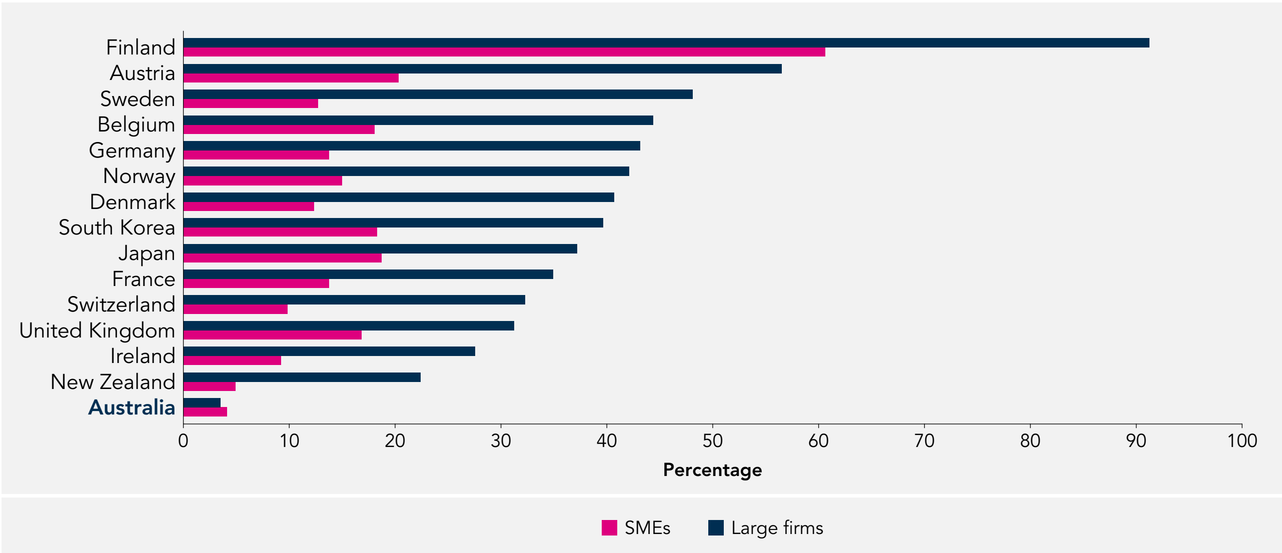
Similar analysis by the ABS, for countries for which data are available but including businesses with 0–9 employees, improves our position to 15th for SMEs and 21st for large firms. Only 13.7 per cent of our large firms collaborated with research organisations: slightly above the level of collaboration—9.6 per cent—by our SMEs (Department of Industry 2013).

Figure 4-5 Percentage of patent applications filed under the Patent Cooperation Treaty with foreign co-inventors, selected countries, 2002 and 2011



Source: OECD Stat, data extracted from international cooperation in patents data set, 26 March 2014.

Figure 4-6 Collaboration on innovation with higher education or public research institutions, by firm size, 2008 to 2010



Notes: By OECD classifications, firms with 10–250 employees are considered SMEs, and firms with more than 250 employees are large firms. Where no data were available for 2008–2010, other years are displayed: Australia 2010–2011, New Zealand 2009–2011, Ireland 2006–2008, Switzerland 2009–2011, Japan 2009–2010 and South Korea 2005–2007.

Source: OECD 2011b.

4.8 CONCLUDING REMARKS

Australian industry is dominated by small to medium business enterprises rather than R&D-intensive multinational enterprises. This industry structure probably influences Australia's patenting profile. Although business funds large amounts of R&D (see Chapter 5), the outcomes of this R&D have not resulted in large numbers of patentable inventions. The low proportion of researchers in businesses (compared with higher education—see Chapter 8) and the low level of business to research collaboration might further limit Australia's capacity to produce new intellectual property with commercial potential.

The majority of patents applied for at the Australian Patent Office are from international patent holders: Australia imports more patentable intellectual property than it produces.

These findings complement those in Chapter 2. Australia has a low to mid-range level of performance in patenting compared with European comparator countries and much lower than the larger economies of the United States, Japan and China. Our performance is poor—particularly when viewed against the dynamic patent activity among Asian nations.

CHAPTER 5

5. RESEARCH FUNDING

This chapter analyses trends in national funding of research and development and compares Australia with selected nations. It deals with funding for R&D allocated by the higher education, business and government sectors.

5.1 MAIN FINDINGS

5.1.1 Gross expenditure on R&D

- Australia's gross expenditure on R&D is higher than that of the smaller European comparator countries but lower than that of the United States, China, Japan, Germany, Korea, France, the United Kingdom and Canada.
- Although Australia's GERD is higher than that of many of the European nations assessed, many of these nations produce more highly cited research publications (as discussed in Chapters 2 and 3).

5.1.2 Higher education expenditure on R&D

- STEM fields account for 73 per cent of Australia's higher education expenditure on R&D. Medical and health sciences account for 29 per cent of HERD, engineering 10 per cent, and biological sciences 9 per cent.
- Australia's HERD increased between 2000 and 2012, as did publication numbers. Despite this, the influence of publications (as measured by field-weighted citation rates) did not improve relative to comparator countries.
- Physics receives a comparatively small amount of investment yet achieves a reasonable output and a high level of field-weighted citations.
- Although medical and health sciences receives the greatest investment and produces the largest number of publications, the field-weighted citation rate for its publications is lower than the rates for the other STEM fields apart from information and computing technology.
- Information and computing technology has the highest cost per publication and a relatively low number of field-weighted citations per publication.
- Applied research accounts for 45 per cent of HERD, pure basic research 23 per cent, and strategic basic research 24 per cent.

5.1.3 Business expenditure on R&D

- STEM fields account for 97 per cent of total business expenditure on R&D. The largest shares are in engineering ($9.3 billion, or 47 per cent of BERD) and information and computer sciences ($5 billion, or 30 per cent).
- Experimental development in the manufacturing and finance sectors accounts for 62 per cent of BERD.
- The manufacturing sector is the largest investor in R&D ($4.8 billion, or 52 per cent of BERD), primarily in engineering ($3.56 billion).
- The mining sector is the second largest investor in R&D ($3.8 billion), also primarily in engineering ($3.6 billion).
- The professional, scientific and technical services sector is the fourth largest investor in R&D ($2.7 billion); ICT tops the investment ($1.1 billion), followed by engineering ($618 million).

5.2 BACKGROUND

Research funding is crucial to a country's R&D system. It influences the shape, scale and focus of the research endeavour. This chapter analyses total expenditure on R&D. Additionally, the analysis extends to funding across the STEM fields (where possible). Comparing STEM funding between countries provides insights into how efficiently countries fund, produce and use research outcomes.

The majority of Australian R&D expenditure is in STEM fields. The distribution of R&D expenditure by industry sector illustrates Australia's STEM effort and how it compares with that of other countries.

5.3 TERMINOLOGY

- Research intensity refers to R&D expenditure as a share of gross domestic product.
- Pure basic research is experimental and theoretical work done in order to acquire new knowledge without looking for long-term benefits other than the advancement of knowledge.
- Strategic basic research is experimental and theoretical work done in order to acquire new knowledge directed at specified broad areas in the expectation of useful discoveries. It provides the broad base of knowledge necessary for the solution of recognised practical problems.
- Applied research is original work done primarily in order to acquire new knowledge with a specific application in view. It is undertaken either to determine possible uses for the findings of basic research or to determine new ways of achieving specific and predetermined objectives.
- Experimental development is systematic work, using existing knowledge gained from research or practical experience, that is directed at producing new materials, products or devices, installing new processes, systems and services, or substantially improving those already produced or installed.

5.4 DATA SOURCES

5.4.1 The OECD Main Science and Technology Indicators database

The funding data used in this chapter were extracted from the OECD's MSTI database (OECD 2011a). The database contains 151 data series selected from the OECD's Scientific and Technological Indicators database for 30 OECD member countries and nine nonmember countries. The database provides a set of indicators that reflect the level and structure of the efforts of OECD member and non-member economies in the field of science and technology from 1981 onwards.

5.4.2 Australian Bureau of Statistics R&D statistics

The Australian data set was compiled from data the ABS collected from Australian higher education institutions in the Survey of Research and Experimental Development. For the higher education sector, the survey is conducted biennially and based on a single calendar–year reference period. In compiling its R&D statistics, the ABS asked institutions to provide data on direct staff inputs (staff directly performing R&D), direct expenditure (expenses directly attributable to R&D), and other staff and resources supporting but not directly performing R&D.

5.4.3 InCites, Thomson Reuters

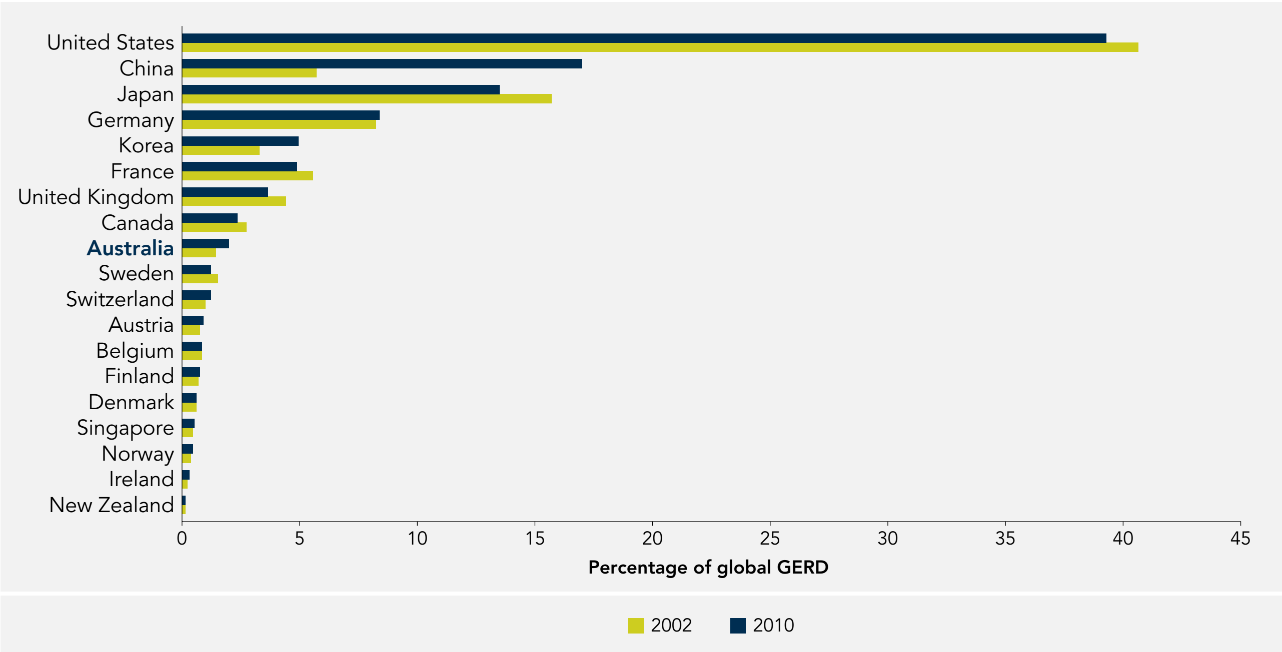
As in Chapter 2, the InCites database was used to analyse author addresses, number of publications, and citations of all publications in the Web of Science database.

5.5 COUNTRIES ANALYSED

As in previous chapters, two groups of benchmarking nations were identified for analysis—countries at stages of development similar to that of Australia and with similar governance systems (the United States, Canada and selected European nations) and selected countries in the Asia–Pacific region.

This chapter compares Australia with the 11 European comparator countries (Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Norway, Sweden, Switzerland and the United Kingdom), North America (Canada and the United States), and countries in our region (China, Japan, South Korea and Singapore).

Figure 5-1 The contribution of selected countries to global expenditure on R&D, 2002 and 2010



Source: OECD Main Science and Technology Indicators, January 2014.

5.6 HOW DOES AUSTRALIA'S R&D INVESTMENT COMPARE?

Research is a global enterprise. Researchers often rely on work done in other countries to generate new knowledge and build on existing knowledge. A nation's expenditure on R&D can reveal where research efforts are focused, allowing for comparisons of Australia's focus with the focus of comparator nations.

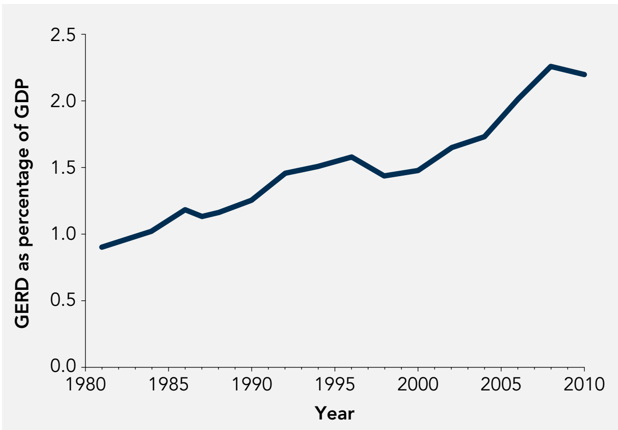
Australia's share of global gross expenditure on R&D increased from 1.4 to 2.0 per cent between 2002 and 2010 (see Figure 5-1). This is more than the smaller European comparator countries but less than the United States, China, Japan, Germany, Korea, France, the United Kingdom and Canada. The United States continues to account for the largest proportion of global R&D funding (about 40 per cent), while China's share of global GERD almost tripled between 2002 (6 per cent) and 2010 (17 per cent).

R&D expenditure as a share of GDP—that is, R&D intensity—is used as an indicator that allows international comparisons to be made. By adjusting R&D investment for economy size, international comparisons can more readily be made. Changes in Australia's R&D intensity over time show the emphasis Australia has placed on developing new knowledge and stimulating innovation.

Australia's R&D intensity rose steadily from 0.9 per cent in 1981 to 2.2 per cent in 2010 (see Figure 5-2). The most rapid growth occurred between 1998 and 2008; since then R&D intensity has fallen slightly. The overall growth reflects an increased focus on R&D in the Australian economy.

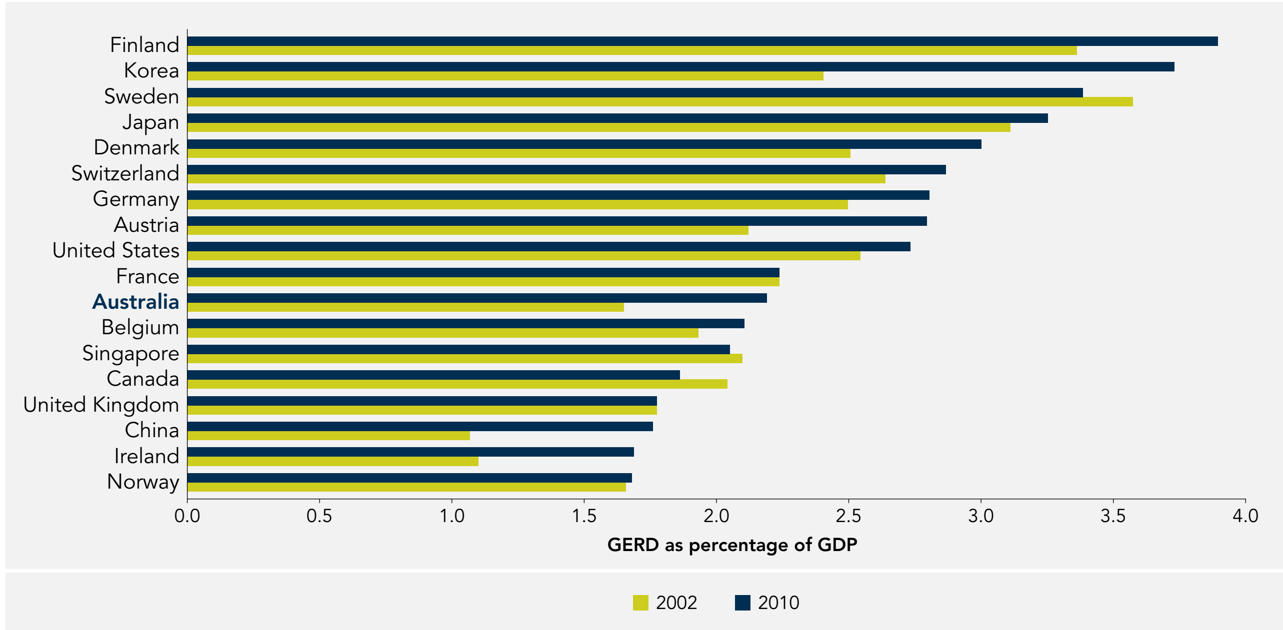
In 2010 Australia's R&D intensity ranked below that of many of the European and Asian comparator nations, but it was higher than Belgium, Singapore, Canada, the United Kingdom, China, Ireland and Norway (see Figure 5-3).

Figure 5-2 Australia's R&D intensity, 1981 to 2010



Source: OECD Main Science and Technology Indicators, January 2014.

Figure 5-3 International R&D intensity, 2002 and 2010



Notes: No data available for 2002 for Sweden—2004 figure given; no data available for 2002 or 2010 for Switzerland—2000 and 2008 figures given.

Source: OECD Main Science and Technology Indicators, January 2014.

5.7 RESEARCH INVESTMENT IN THE AUSTRALIAN HIGHER EDUCATION SECTOR

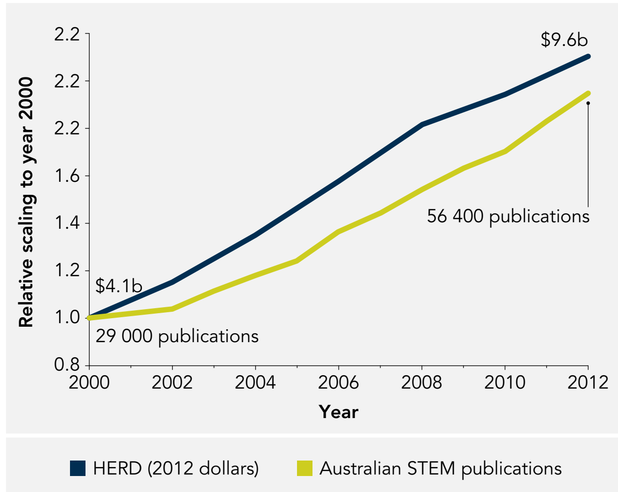
HERD accounts for a quarter of Australia's total research expenditure (ABS 2010). This does not include the proportion of student-related funding distributed by government that universities use to subsidise research either directly through the employment of research-active staff or indirectly through the provision of infrastructure and facilities.

The higher education sector's research output is measured in part by the number of STEM research publications (see Figure 5-4). Since the year 2000 Australia's total HERD and the number of publications in STEM fields have almost doubled.

The average field-weighted citation rate for Australian STEM publications has also increased, but is still at the lower end of the selected European comparator nations (see Figure 5-5).

Taken together, this shows that Australia's increased investment in research has resulted in more publications. There has also been an increase in the citation rate, although the increase is on par with that of the European comparator nations.

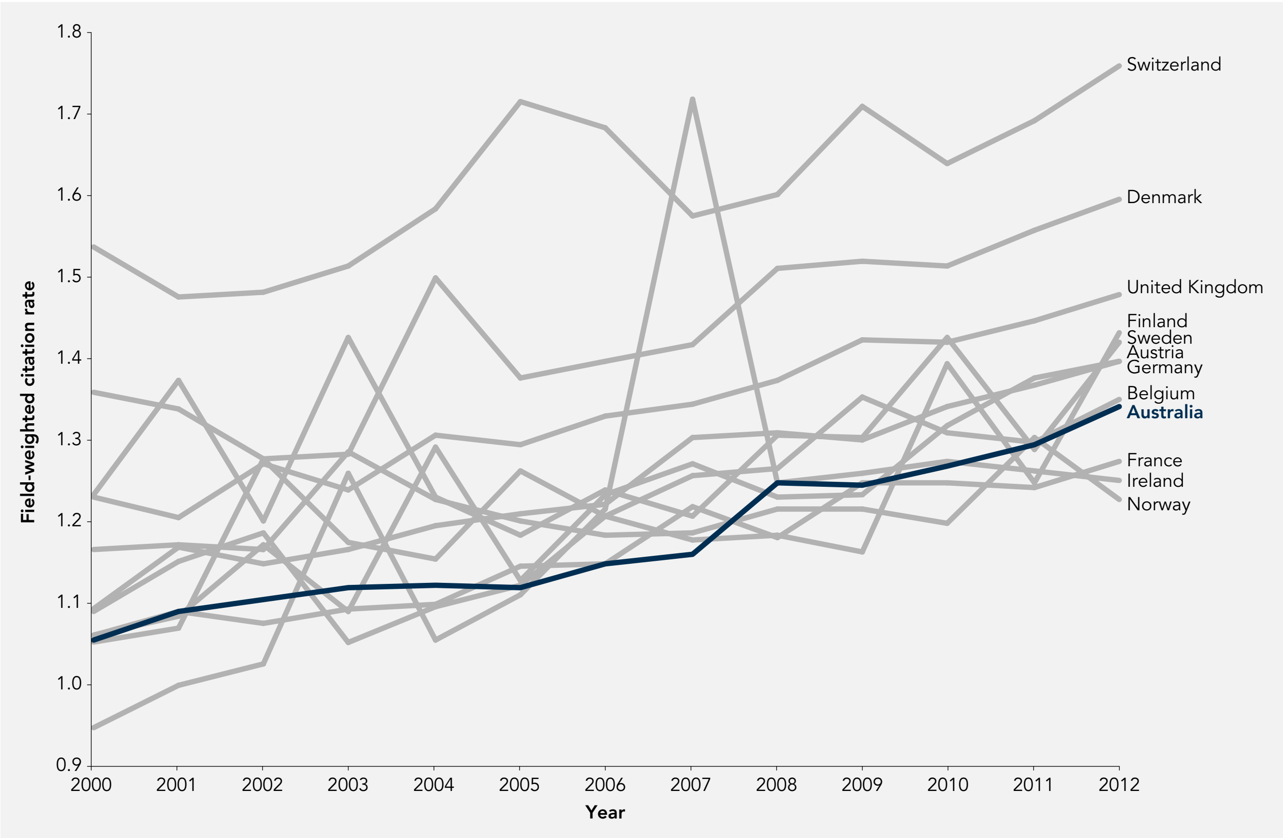
Figure 5-4 HERD and STEM publication output



Notes: HERD and publication data are expressed relative to the year 2000 and are given a value of 1. The blue line represents HERD expenditure (2012 dollars calculated as chain volume, data collected every two years); the yellow line shows the total publications produced in STEM fields (consistent with the Chapter 2 analysis).

Source: ABS (2013); InCites, Thomson Reuters (2012); Global Comparisons Dataset, compare subject areas in institutions (Australia totals), 2000–2012. Report created 10 March 2014; data processed 3 July 2013. Data from Web of Science.

Figure 5-5 Citation rates for Australian and selected European countries' STEM publications, 2000 to 2012



Notes: STEM fields are selected using Australia ERA 2012 FoR Level 1 categories mathematical sciences, physical sciences, chemical sciences, earth sciences, environmental sciences, biological sciences, agricultural and veterinary sciences, information and computing sciences, engineering and technology, and medical and health science. Annual STEM citation rates are calculated as the simple average across these fields.

Source: Thomson Reuters (2012); Global Comparisons Dataset, compare subject areas, 2000–2012. Report created 9 October 2014; data processed 31 March 2014. Data from Web of Science.

5.8 THE COST OF AUSTRALIAN STEM R&D PUBLICATIONS

The indicative relationship between funding and research output can be explored by assessing research investment, publication output and citation rates for the various STEM fields.

Figure 5-6 shows HERD data for the STEM fields for 2008, 2010 and 2012 (the years for which the most recent data are available) compared with each field's average field-weighted citation rate for 2009, 2011 and 2013. The differing periods of analysis for HERD and publication citation rates allow for the lag between when research expenditure and activity occur and when the outcomes of that research are published and begin to be cited. This lag can vary considerably between fields of research as well as within fields, depending on the complexity and nature of the research. The one-year lag chosen here might be regarded as nominal for simple comparison purposes.

When compared with other fields, physics receives a relatively small investment in the higher education sector, but it achieves a high level of citations. Medical and health sciences receives the greatest investment and produces the largest number of publications, yet it receives fewer average citations than all but one of the STEM fields (information and computing technology), all of which receive a lower level of investment.

If a field (for example, medical and health sciences) has a relatively low average citation rate this might be a reflection of a large publication output, which typically reduces the average citation rate for the field.

As shown in Chapter 3, medicine was the largest field contributing to Australian publications in the global top 1 per cent of STEM publications, although every field of research contributes publications that are cited in the top 1 per cent of STEM publications.

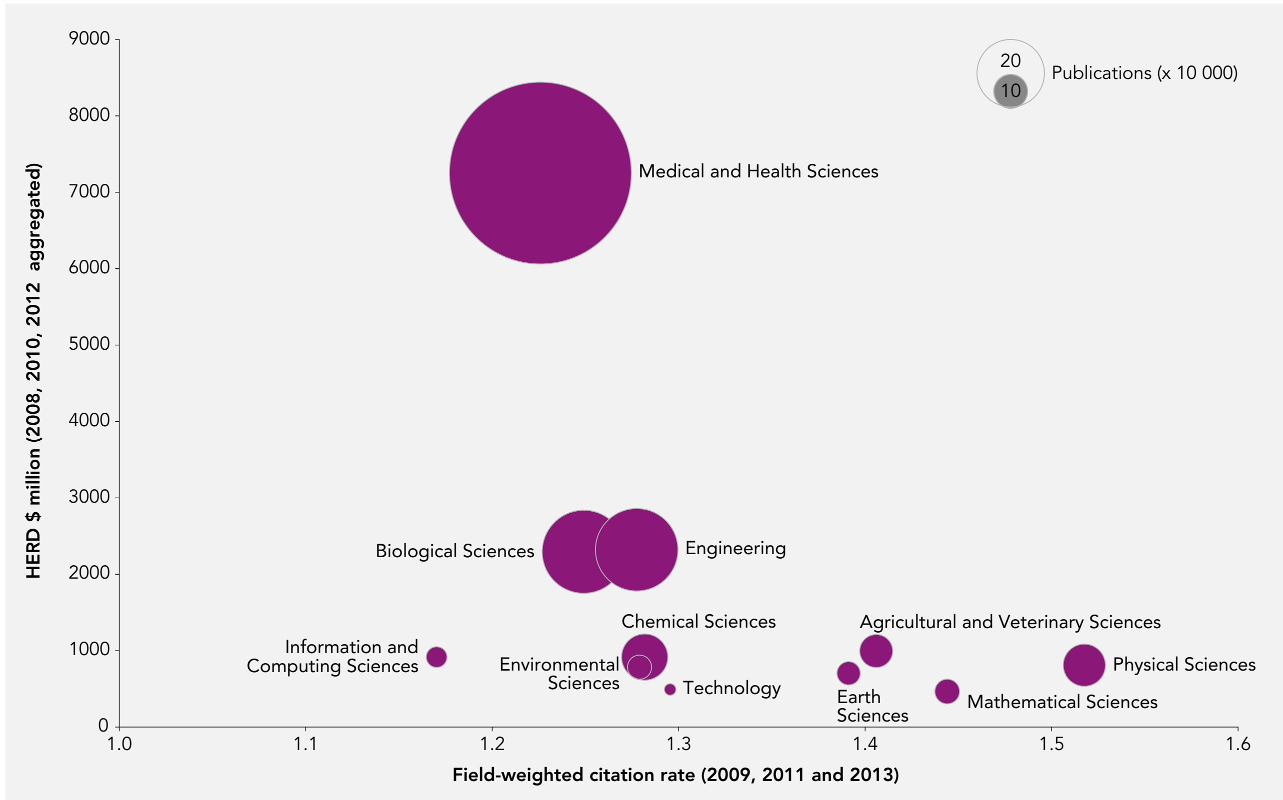
It should be noted that medical research institutes are included in the higher education sector only if they are part of a university. As a result, only part of these institutes' investment in medical and health sciences is included in this analysis of HERD, despite their publications and citations being included. If the funding associated with private medical research institutes was included, it would increase the total funding for medical and health sciences shown in Figure 5-6.

This analysis can be extended to reflect the indicative cost per publication, on average, during the period.

Information and computer sciences had the highest cost per publication and low average citation rates per publication compared with other fields (see Figure 5-7). The cost per publication in medical and health sciences is also high. This complements the data in Figure 5-6 and shows that the field has high amounts of expenditure resulting in high numbers of publications but also a high cost per publication. By contrast, physics and mathematics have lower costs per publication but higher citation rates.

This comparison is indicative of relative overall costs for research in STEM fields. It does not provide an account of the nature of these costs—for example, the spread between infrastructure, consumables and other costs, which can vary widely between fields.

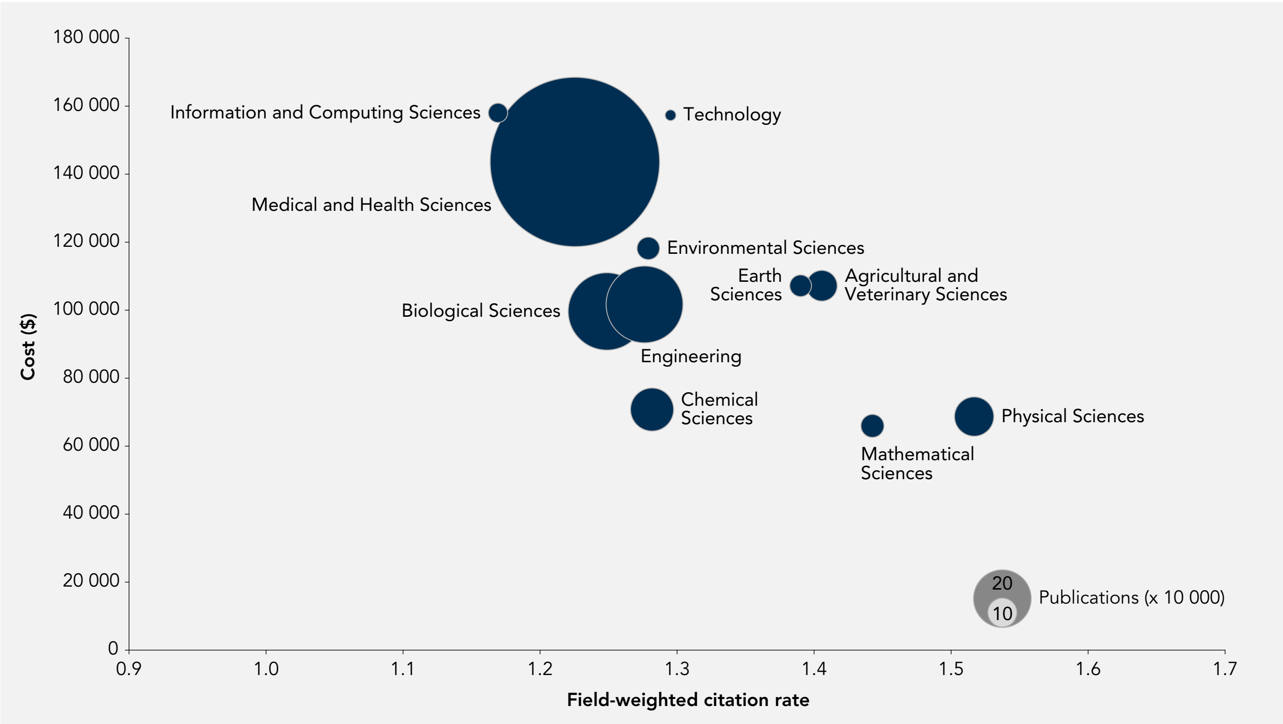
Figure 5-6 Higher education R&D expenditure and publication citation rates, by field



Notes: Dollars per publication calculated using 2008, 2010 and 2012 HERD and 2009, 2011 and 2013 bibliometric data to account for the lag between funding and publication. Circle size represents the number of publications during the period.

Source: ABS (2013).

Figure 5-7 Cost per publication and citation rate, by field



Notes: Cost per publication is calculated using 2008, 2010 and 2012 HERD and 2009, 2011 and 2013 bibliometric data to account for the lag between funding and publication. Circle size represents number of publications during the period.

Source: ABS (2013).

5.9 R&D EXPENDITURE BY FIELD AND SOCIO-ECONOMIC OBJECTIVE

Businesses and higher education institutions are pivotal in the Australian innovation system and each have their own distinctive profile of R&D investment. This section looks at the focus and funding of R&D in the two sectors.

Expenditure on R&D can be broken down by fields of research to show how the higher education, business and government sectors use the funds (see Table 5-1). Investment in STEM fields accounts for 97.3 per cent of total business expenditure on R&D, most of this goes to engineering (47.4 per cent) and information and computing sciences (30 per cent).

The Australian Bureau of Statistics categorises R&D expenditure data by socio-economic objectives, which reflect the purpose of the R&D as identified by the data provider (the researcher or business).

About half (49 per cent) of HERD is used to support research with 'society' objectives (see Figure 5-8); a further 16 per cent supports the objective of expanding knowledge. Health accounts for the largest single objective (32 per cent of HERD). Within the 'economic development' group of objectives, manufacturing, information and communication services, and economic framework attract the greatest amount (about 5 per cent each).

The largest proportion of BERD is associated with the 'economic development' categories, and there is minimal expenditure on the 'society' categories. The largest individual socio-economic objectives are manufacturing (25 per cent of BERD) and commercial services and tourism (21 per cent). Mineral research and energy also attract large shares of BERD (15 and 13 per cent respectively).

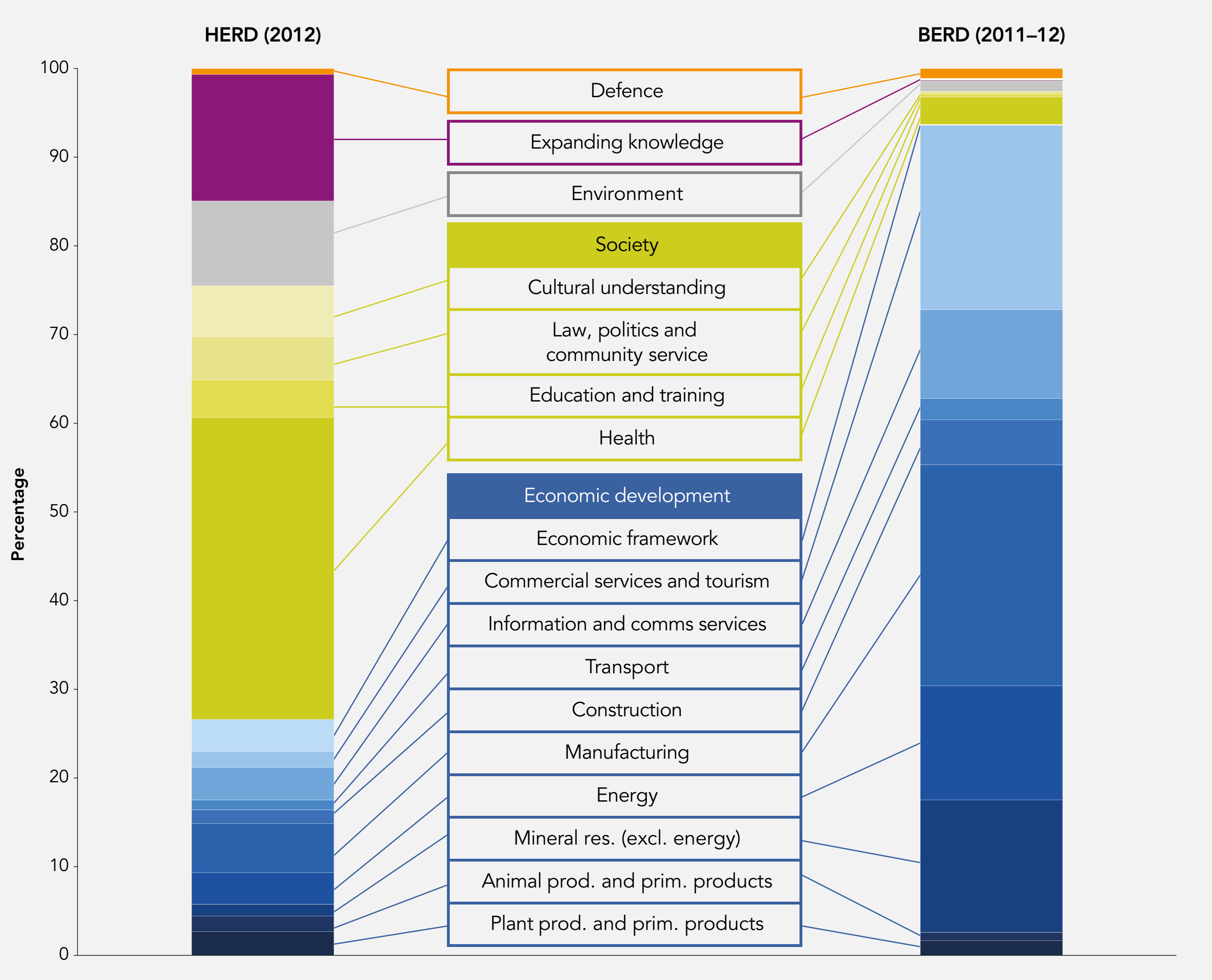
Table 5-1 Australian research expenditure, by sector

	HERD (2012)		BERD (2011–12)		GOVERD (2011–12)	
Field	$ million	%	$ million	%	$ million	%
Total	**9 609**	..	**18 321**	..	**3725**	..
STEM	6 978	72.6	17 833	97.3	3303	93.5
STEM excluding Medical and Health Sciences	4 156	43.2	16 891	92.2	2820	79.8
Humanities and Social Sciences	2 632	27.4	489	2.7	230	6.5
Breakdown of STEM	$ million	%	$ million	%	$ million	%
Agricultural and Veterinary Sciences	394	4.1	455	2.5	570	16.1
Biological Sciences	841	8.7	113	0.6	364	10.3
Chemical Sciences	358	3.7	426	2.3	165	4.7
Earth Sciences	288	3.0	122	0.7	207	5.9
Engineering	955	9.9	8 686	47.4	536	15.2
Environmental Sciences	342	3.6	281	1.5	247	7.0
Information and Computing Sciences	331	3.4	5 496	30.0	324	9.2
Mathematical Sciences	168	1.7	29	0.2	54	1.5
Medical and Health Sciences	2 823	29.4	941	5.1	483	13.7
Physical Sciences	312	3.2	47	0.3	238	6.7
Technology	168	1.7	1 235	6.7	115	3.2

.. Not applicable.

Sources: ABS (2012a, 2012b, 2013).

Figure 5-8 HERD and BERD, by socio-economic objective



Sources: ABS (2012a, 2013).

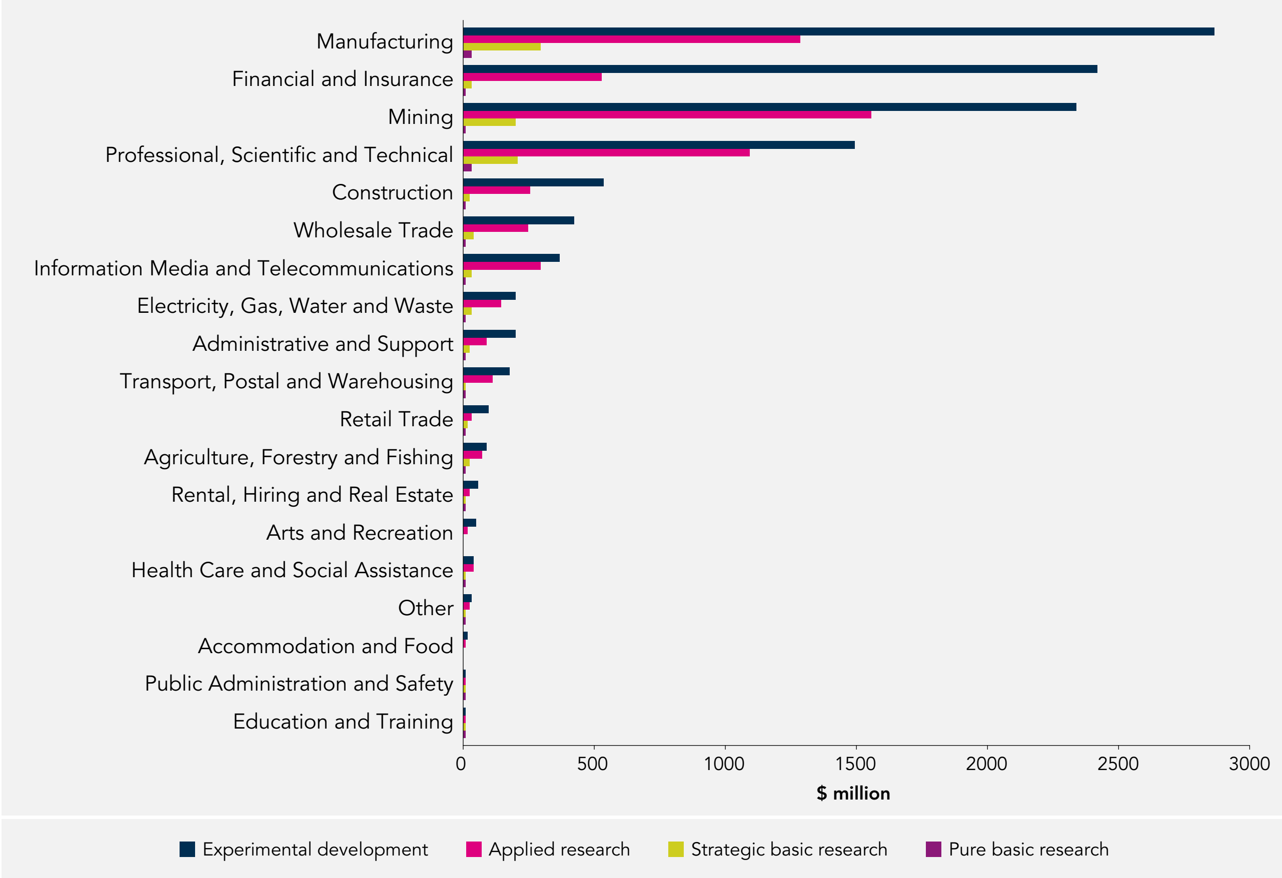
5.10 R&D EXPENDITURE BY INDUSTRY SECTOR AND ACTIVITY TYPE

The largest industry sectors for BERD are the manufacturing and finance sectors, followed by the mining and scientific services sectors (see Figure 5-9). Experimental development is the largest type of R&D activity in these industry sectors, accounting for 62 per cent of BERD across all sectors. Applied research is the next most common type of activity, accounting for 32 per cent of total BERD.

HERD can also be classified by type of R&D activity (see Figure 5-10). Applied research dominates at 45 per cent; it is followed by pure basic research (23 per cent) and strategic basic research (24 per cent). In contrast with BERD, only a small amount of HERD (8 per cent) is associated with experimental development.

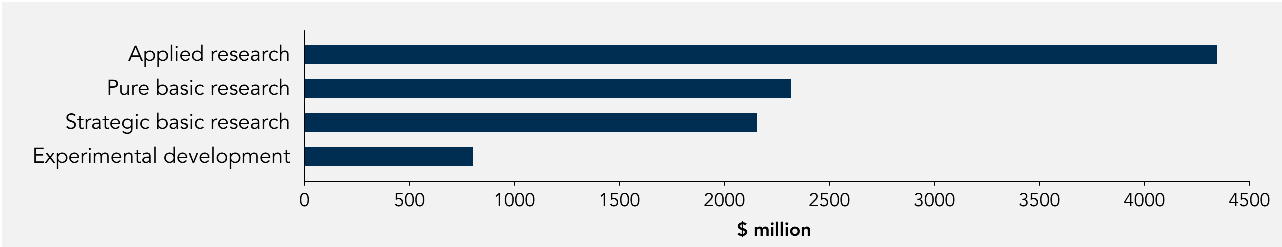
Both HERD and BERD have a strong focus on applied research. Businesses have the bigger focus on experimental development. Both strategic and pure research are important for higher education institutions, but neither is a focus in the business sector.

Figure 5-9 Business expenditure on R&D by activity type, 2011–12



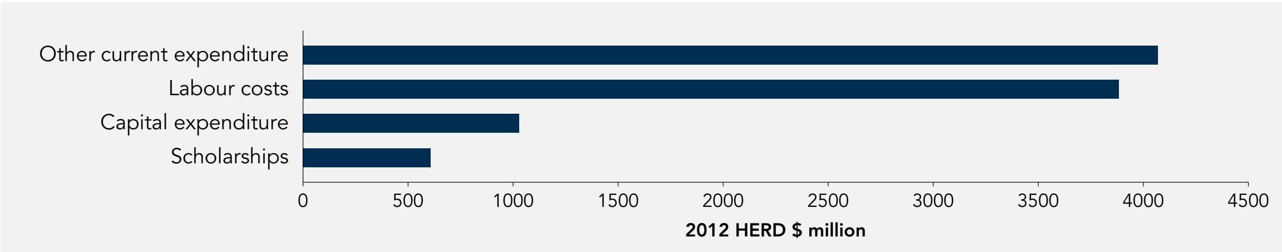
Source: ABS (2012a).

Figure 5-10 Higher education expenditure on R&D, by activity type, 2012



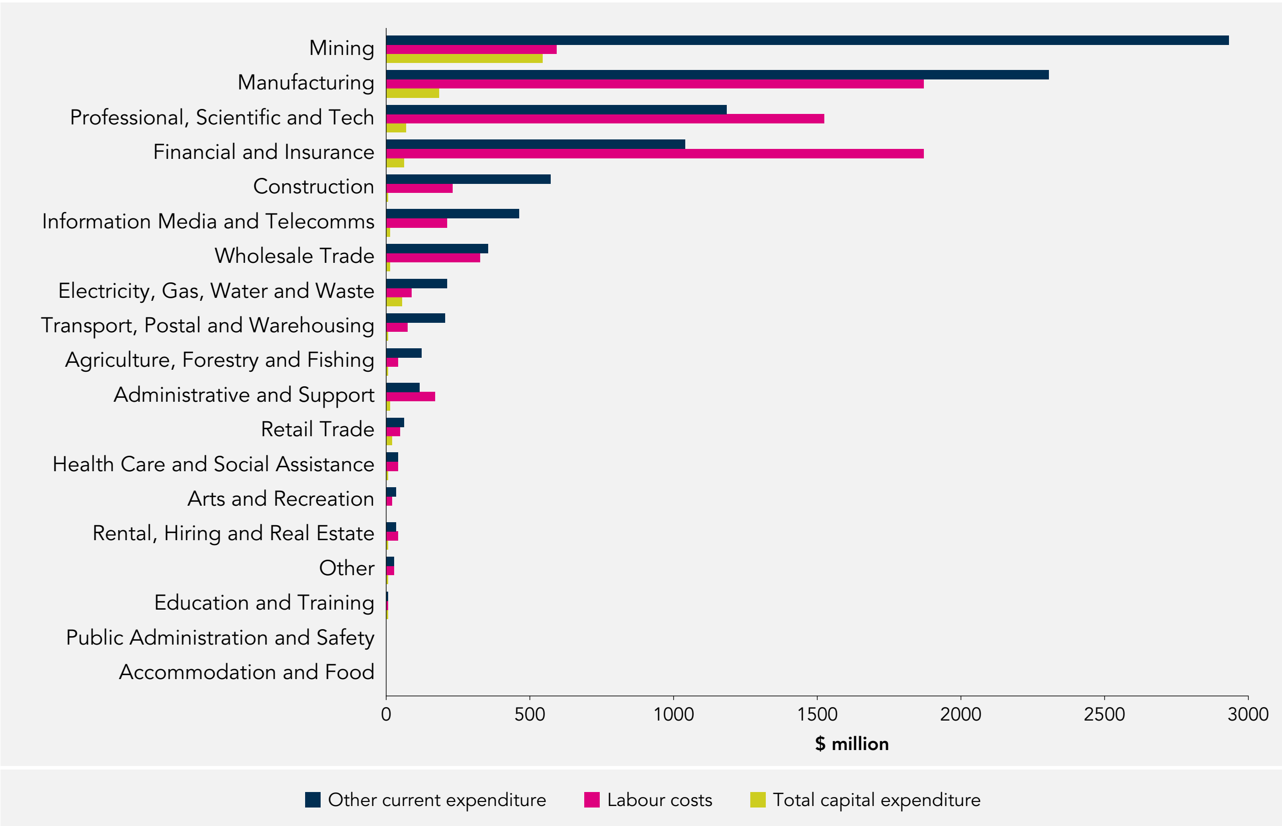
Source: ABS (2013).

Figure 5-11 Higher education expenditure on R&D, by expenditure class, 2012



Source: ABS (2013).

Figure 5-12 Business expenditure on R&D, by expenditure type, 2011–12



Source: ABS (2012a).

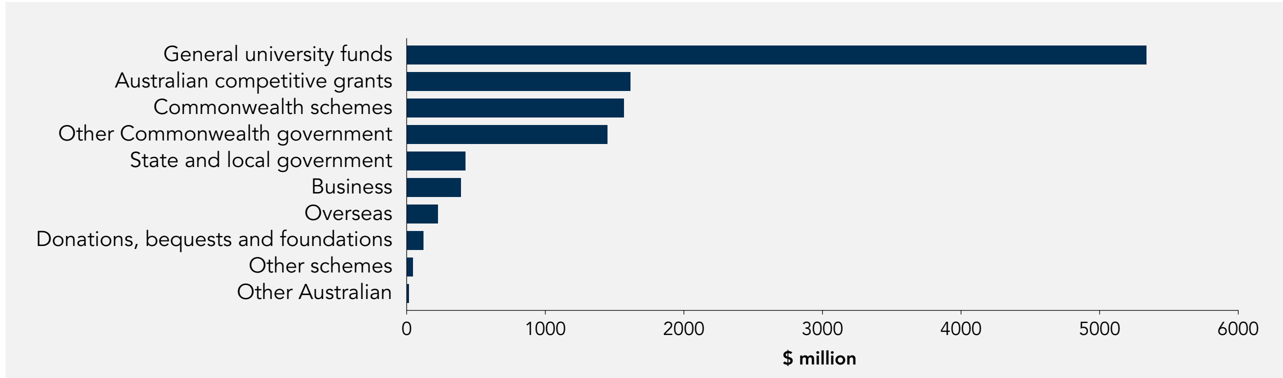
5.11 HERD AND BERD BY EXPENDITURE CLASS

Examination of the allocation of expenditure to capital, labour and other areas offers insights into the R&D profiles of businesses and higher education institutions.

The largest higher education share of expenditure, 42 per cent, is associated with items such as materials, fuel, water, rent and others (other current expenditure, at $4079 million—see Figure 5-11). Labour accounts for 41 per cent of HERD ($3890 million) and capital accounts for 11 per cent ($1031 million).

Figure 5-12 shows that capital attracts the smallest amount of R&D expenditure for most industry sectors. The mining sector is an exception, investing $563 million in capital in 2011–12. Labour costs represent a large component of BERD in the manufacturing, finance, and professional and scientific services sectors.

Figure 5-13 Higher education expenditure on R&D, by source of funds, 2012



Source: ABS (2013).

5.12 SOURCES OF HERD FUNDING

HERD can be further analysed by looking at the source of funding (see Figure 5-13). The largest source of funds is general university funds, at 48 per cent; this is followed by competitive grants and other Commonwealth funding sources (14 per cent each).

Although business funds only a small proportion of HERD (4 per cent), this still amounted to $398 million in 2012. Business-funded HERD includes R&D grants from industry, payments for R&D projects carried out under contract on behalf of businesses, and funding from incorporated cooperative research centres.

This business funding of R&D activity in the higher education sector is small in comparison with total BERD ($18 billion in 2011–12) and reflects a low level of business–university collaboration (see Chapter 4). The investment of nearly $400 million is, however, by no means insignificant when compared with individual funding sources for the higher education sector. For example, in 2012–13 the Australian Research Council awarded a total of $529 million to 1168 new grants under the Discovery Program (ARC 2013).

5.13 FIELDS OF RESEARCH THAT ARE IMPORTANT TO INDUSTRY

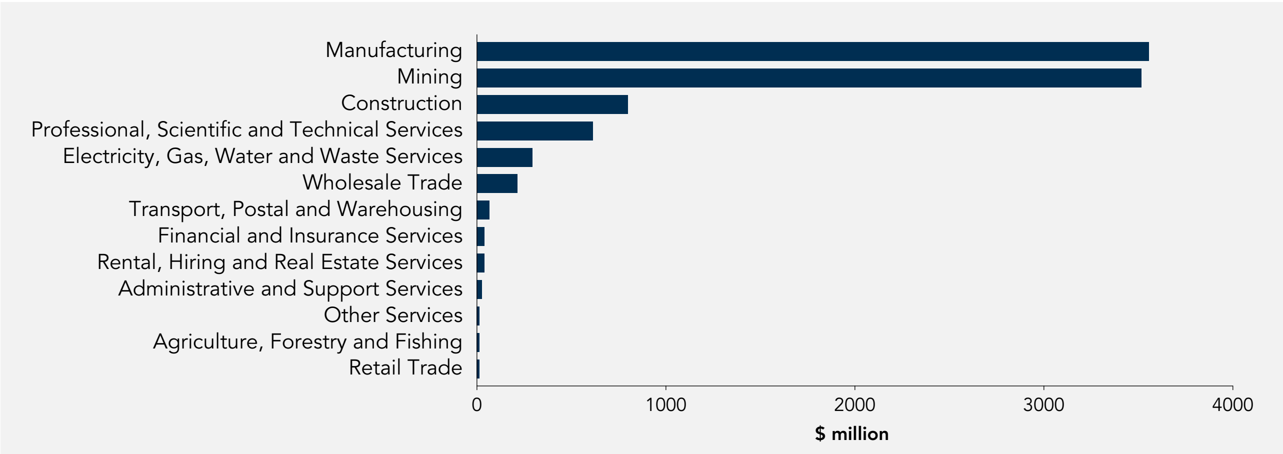
In Australia the STEM fields account for the largest share of business R&D, attracting 96.8 per cent of BERD in 2010–11. Engineering and information technology attracted the largest shares, with $9.3 billion and $5 billion respectively.

So how do different industry sectors invest in engineering and IT, and what are the main research fields that attract R&D investment by different industry sectors?

5.13.1 Industries that use engineering

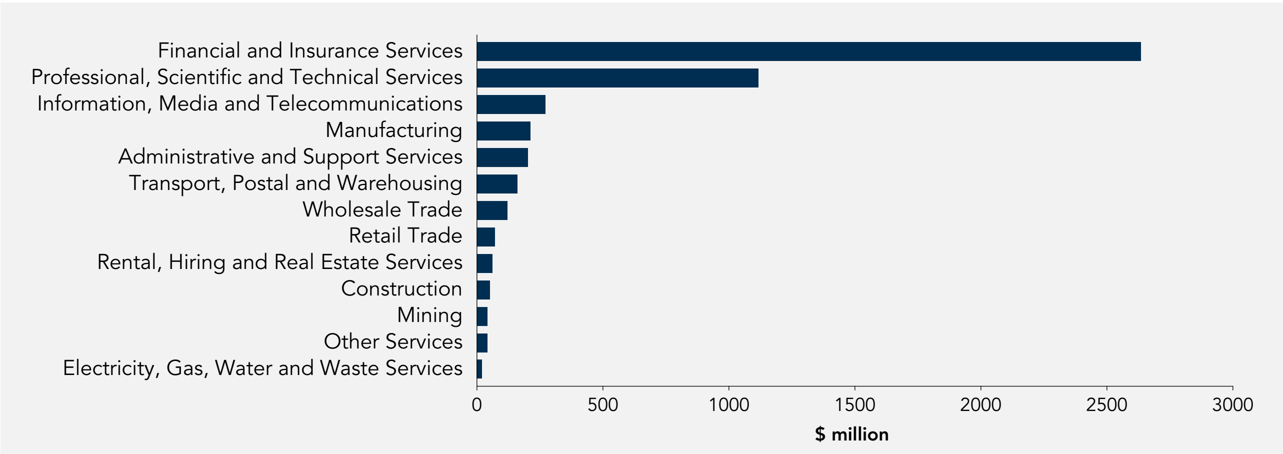
As the largest individual field of research underpinning Australian industry research, engineering is important to the innovation capacity of Australian business. The industry sectors with the largest investments in engineering R&D are the manufacturing and mining sectors, with $3.56 billion and $3.52 billion of BERD respectively in 2010–11 (see Figure 5-14). These two sectors contribute about 38 per cent of total BERD to engineering R&D. Construction and the professional, scientific and technical services industry sectors spend about $802 million (9 per cent of BERD) and $618 million (7 per cent of BERD) respectively. The utilities sector (electricity, gas, water and waste services) invests $295 million in engineering R&D. This shows that, although the large sectors of the Australian economy, such as manufacturing and mining, are the main players in engineering-based R&D, engineering is also an important field for other industry sectors.

Figure 5-14 Business expenditure on engineering R&D, by industry sector, 2010–11



Source: ABS, Business expenditure on R&D [data available on request].

Figure 5-15 Business expenditure on IT R&D, by industry sector, 2010–11



Source: ABS, Business expenditure on R&D [data available on request].

Information technologies represent the second largest field of research underpinning Australian BERD, attracting a total of $5 billion in 2010–11. The industry sector with the largest investment in IT R&D is financial and insurance services, with approximately $2.6 billion of expenditure in 2010–11 (see Figure 5-15). This sector accounts for 53 per cent of the total BERD directed to IT R&D. The industry sector with the second largest investment in IT R&D is professional, scientific and technical services, with over $1.1 billion of expenditure (22 per cent of total IT BERD). The information, media and telecommunications sector spends about $270 million, while manufacturing spends $209 million on IT R&D. It is thus evident that, as with engineering, a range of Australian industry sectors invest in IT R&D.

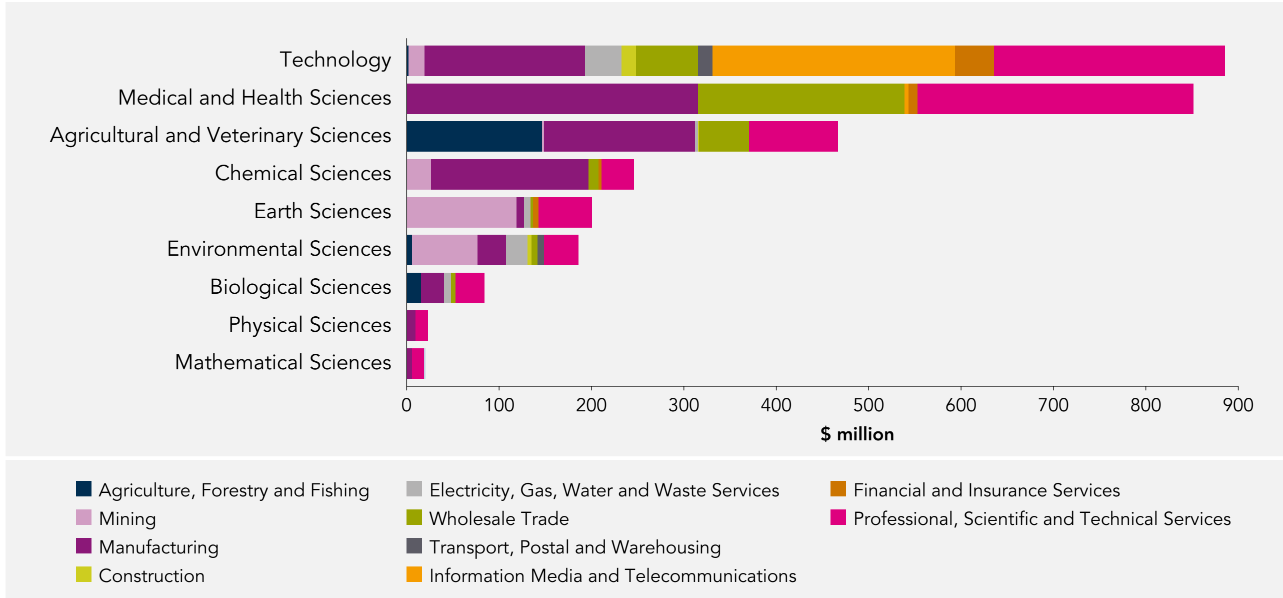
5.13.2 Business use of other fields of research

As demonstrated in previous chapters, Australia has a broad range of research capability. While engineering and IT together account for 80 per cent of BERD, there is nevertheless $3.6 billion of industry research in other fields. Figure 5-16 shows the breakdown of investment in each field of research by industry sector. It excludes the fields of engineering and IT because of the distorting effect of these large investments. The largest of the other fields of research is technology, with research based on technology done by professional, scientific and technical services ($249 million), information, media and telecommunications ($262 million) and manufacturing ($175 million). Six other industry sectors invest in technology-based R&D, totalling $208 million.

Medical and health sciences is the next largest category, with investment from three main industry sectors—scientific services ($299 million), wholesale trade ($224 million), and manufacturing ($175 million). Manufacturing invests more in agricultural R&D ($164 million) than the agriculture, fisheries and forestry sector ($146 million). Biology, chemistry, environmental sciences and earth sciences attract investment from a range of industry sectors, reflecting the fundamental nature of these fields. There are only small amounts of industry R&D investment in physics and mathematics. This could be a result of the way industry thinks about these fields, rather than an absence of R&D in these areas. For example, engineering and IT build on theoretical frameworks established in mathematics and physics. It is also not surprising that industry invests little in fields such as mathematics and physics, focusing instead on fields with more direct application, such as engineering and IT.

Collectively, these data show that the major industry sectors that perform large amounts of R&D rely on a broad range of fields.

Figure 5-16 Business expenditure on fields of research, by industry sector, 2010–11



Note: Excludes engineering and information and computing sciences, the two dominant sectors, and industry categories with low R&D expenditure.
Source: ABS, Business expenditure on R&D [data available on request].

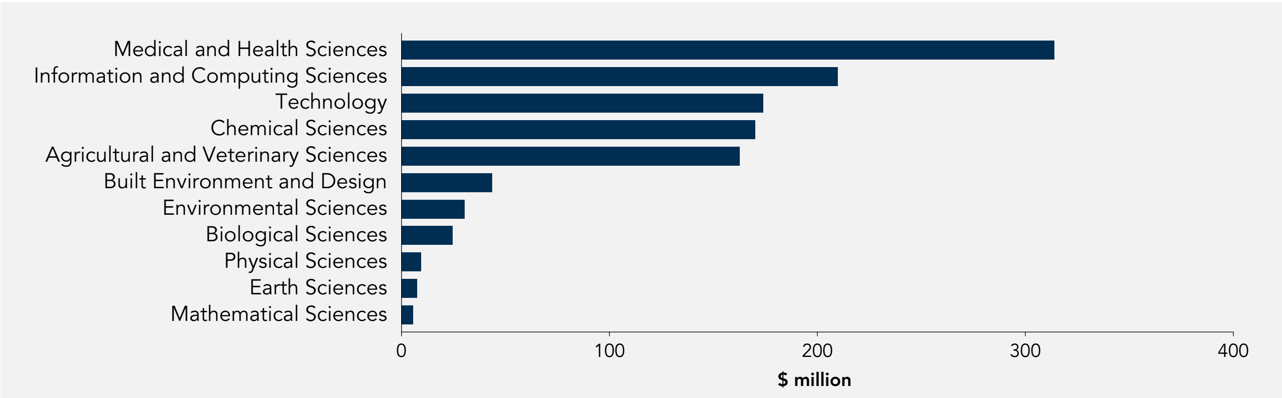
5.14 FIELDS OF RESEARCH THAT ARE IMPORTANT TO MAJOR INDUSTRY SECTORS

Australian industry relies on a range of fields to support its R&D needs. But how does the R&D need of industry vary from sector to sector?

5.14.1 The manufacturing sector

The Australian manufacturing sector is the single largest business investor in R&D, spending $4.8 billion in 2010–11. This constitutes 52 per cent of total BERD. The largest single field for R&D investment by the manufacturing industry is engineering, at $3.56 billion. While this represents 76 per cent of total R&D expenditure by the manufacturing sector, there is a further $1.1 billion spread across multiple fields (see Figure 5-17). The second largest field of research is medical sciences, with $314 million; this is followed by information and computing sciences ($210 million). Technology, chemistry and agricultural sciences each have about $170 million of expenditure.

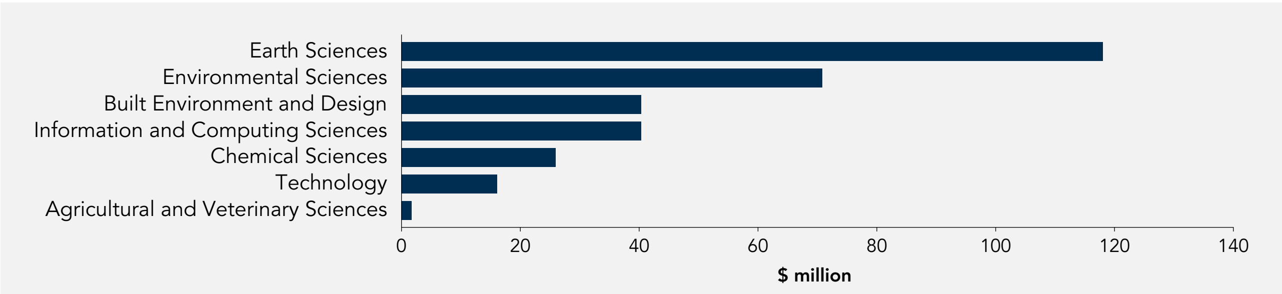
Figure 5-17 Manufacturing sector expenditure on R&D, by field, 2010–11



Note: Not shown is investment in engineering R&D by the manufacturing sector ($3.56 billion).

Source: ABS, Business expenditure on R&D [data available on request].

Figure 5-18 Mining sector expenditure on R&D, by field, 2010–11



Note: Not shown is investment in engineering R&D by the mining sector ($3.5 billion).

Source: ABS, Business expenditure on R&D [data available on request].

Altogether, this paints a picture of an R&D-intensive manufacturing sector that produces knowledge, goods and services by relying primarily on engineering R&D but also on the medical, agricultural, chemical and technology fields, as well as fundamental fields.

5.14.2 The mining sector

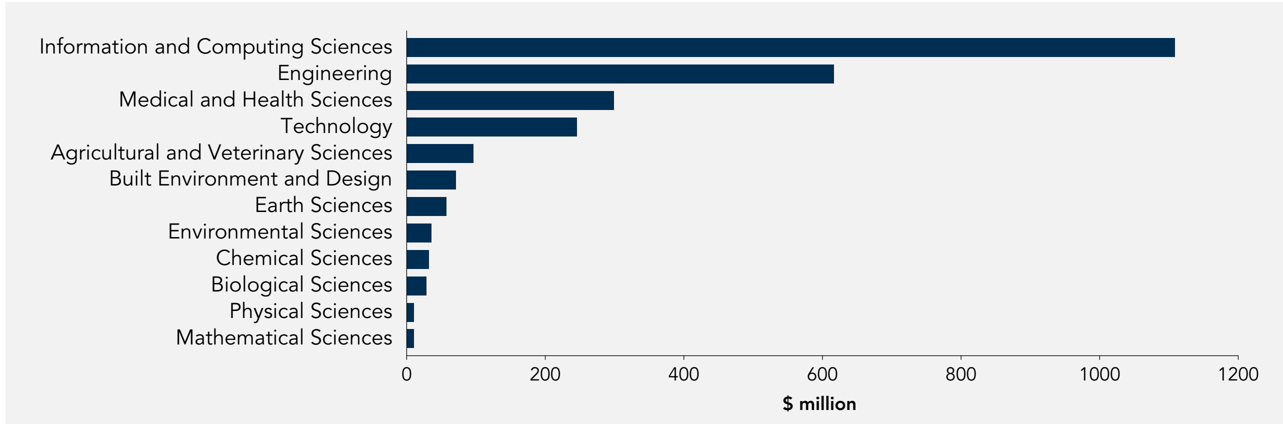
The mining sector is the second largest R&D investor, with over $3.8 billion in expenditure in 2010–11. Again, the field that attracts the largest investment is engineering, accounting for $3.5 billion. A further $313 million in investment is spread across earth sciences ($118 million), environmental sciences ($71 million), built environment and design ($40 million), information and computing sciences ($40 million) and chemical sciences ($26 million) (see Figure 5-18).

This is a similar profile to that for the manufacturing sector, with a large amount of R&D investment directed primarily to engineering and investment in a range of other scientific fields.

5.14.3 The professional, scientific and technical services sector

Businesses in the professional, scientific and technical services sector are typically specialised and sell their expertise. In most cases, equipment and materials are not major inputs (ABS 2006). The activities involved generally require a high level of training and formal (usually tertiary-level) qualifications. These services include scientific research, architecture, engineering, computer systems design, law, accountancy, advertising, market research, management and other consultancy, and veterinary science (ABS 2006).

Figure 5-19 Professional, scientific and technical services expenditure on R&D, by field, 2010–11



Source: ABS, Business expenditure on R&D [data available on request].

The professional, scientific and technical services sector is the fourth largest investor in R&D, with $2.7 billion in expenditure in 2010–11.[2] The fields that attract the largest amounts of investment are again information and computing sciences ($1.1 billion) and engineering ($618 million). There is a wide distribution of the remaining scientific fields, with investment in almost all fields (see Figure 5-19).

5.15 CONCLUDING REMARKS

The business and higher education sectors occupy separate but partially connected parts of our innovation system. This reflects their different roles, priorities and research strengths.

Collaboration between Australian businesses and researchers in public sector institutions and universities is low by OECD standards (see Chapter 4).

The R&D profiles of the business and higher education sectors complement each other and overlap at a very low level and are differentiated at key stages of the innovation pipeline. Links exist because the developmental end of the innovation pipeline (occupied largely by business) depends on a supply of human capital and new knowledge from basic and applied research (the higher education end of the pipeline).

2 The financial services sector is the third largest investor in business R&D, accounting for $2.77 billion in expenditure, which is almost solely focused on information sciences (over 95 per cent of the sector's R&D).

CHAPTER 6

6. INTERNATIONAL COLLABORATION

This chapter explores Australia's collaboration with international researchers in connection with STEM publications. It uses the number of and citation rates for publications to assess trends in STEM publications co-authored by Australian researchers and their international colleagues.

6.1 MAIN FINDINGS

- On average, co-authorship with international partners produced publications with higher citation rates than the average for STEM publications from Australia, and most of the comparator countries.
- The proportion of all Australian STEM publications with an international co-author increased between 2002 and 2012 but not as much as was the case in most of the comparator countries.
- Each European comparator country has a greater proportion of total STEM publications with an international co-author than Australia.
- With the exception of the United States, India and China, in all the countries considered more than 50 per cent of their top 1 per cent of highly cited publications in natural science and engineering in 2010 to 2012 was with an international co-author.
- In general, international collaboration correlates with higher citation rates for publications in biomedical and clinical health, Australia's largest research field, compared with the average of all STEM publications for all countries.

6.2 BACKGROUND

Australia has long sought and benefited from access to leading researchers and research facilities overseas. Our size and geography pose challenges that leading research nations in, say, the European Union do not face, but they also offer a greater opportunity to collaborate with countries in our region—for example, through existing bilateral research agreements with China and India (Department of Industry n.d.).

International collaboration in STEM can occur at a number of levels, from collaboration between individuals to joint research projects, sharing research infrastructure, opening access to research data and linking research centres and potentially virtual networks (AUCC 2009). It enables researchers to work with other people in their field and participate in networks focused on cutting-edge activity (Adams et al. 2007). Science has always been international, but the rate of its internationalisation has accelerated in recent decades (Wissenschaftsrat 2010). Suggested reasons for the increase in international collaboration are increased research costs, especially in areas requiring specialised equipment or infrastructure, and the global nature of challenges such as climate change and pandemics.

Among the benefits of international collaboration in research are expanding researchers' capacity to respond to complex problems by drawing on diverse skills and perspectives (National Science Foundation 2014), reducing unnecessary duplication of research effort, and broadening the scale and scope of research teams (Matthews et al. 2009). An important question then arises: is it possible to measure and benchmark the benefits of international collaboration?

In Chapter 2 bibliometric analysis is used to benchmark research performance; this tool can also be applied to measuring the outcome of research collaboration. It is, however, important to recognise that the citation rate is but one element in assessment of the productivity of collaboration (Matthews et al. 2009).

6.3 DATA SOURCES

This chapter uses the same data sets as used for Chapters 2 and 3—InCites, Thomson Reuters 2002 to 2012, and Scopus. The data were extracted from the InCites database between January and March 2014. The biomedical and clinical health sciences field cluster is extracted from the broader medical and health sciences data and analysed separately because of its large size as a field (based on total number of publications), which could skew the overall result. The BCH field cluster was defined and evaluated by the Excellence in Research for Australia initiative in 2010. Appendix A provides details.

6.4 COUNTRIES ANALYSED

As in previous chapters, two groups of benchmarking nations were identified for analysis—countries at stages of development similar to that of Australia and with similar governance systems (the United States, Canada and selected European nations) and selected countries in the Asia–Pacific region.

Australia is compared with the European comparator nations (Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Norway, Sweden, Switzerland and the United Kingdom), North America (Canada and the United States) and countries from the Asia–Pacific region (New Zealand and China, India, Indonesia, Japan, Malaysia, the Philippines, Singapore, South Korea, Thailand and Vietnam).

6.5 DATA ANALYSIS

To investigate whether there is an association between international collaboration and research performance, the number of and field-weighted citation rates for Australian publications with or without international co-authors were compared with those for other countries.

6.5.1 The trend in Australian STEM publications with international co-authorship

From 2002 to 2012 the number of Australian STEM publications written with one or more international co-authors rose from 9395 to 21 907, a 133 per cent increase (see Figure 6-1); this compares with an increase from 21 358 to 38 609 (81 per cent) in the total number of Australian STEM publications.

The proportion of Australia's total STEM publications with international co-authorship is increasing. Between 2002 and 2012 it rose from 45 to 57 per cent (see Table 6-1), showing that international collaboration is playing an increasingly important role in Australian STEM research.

Table 6-1 Proportion of total Australian STEM publications with international co-authorship, 2002 to 2012

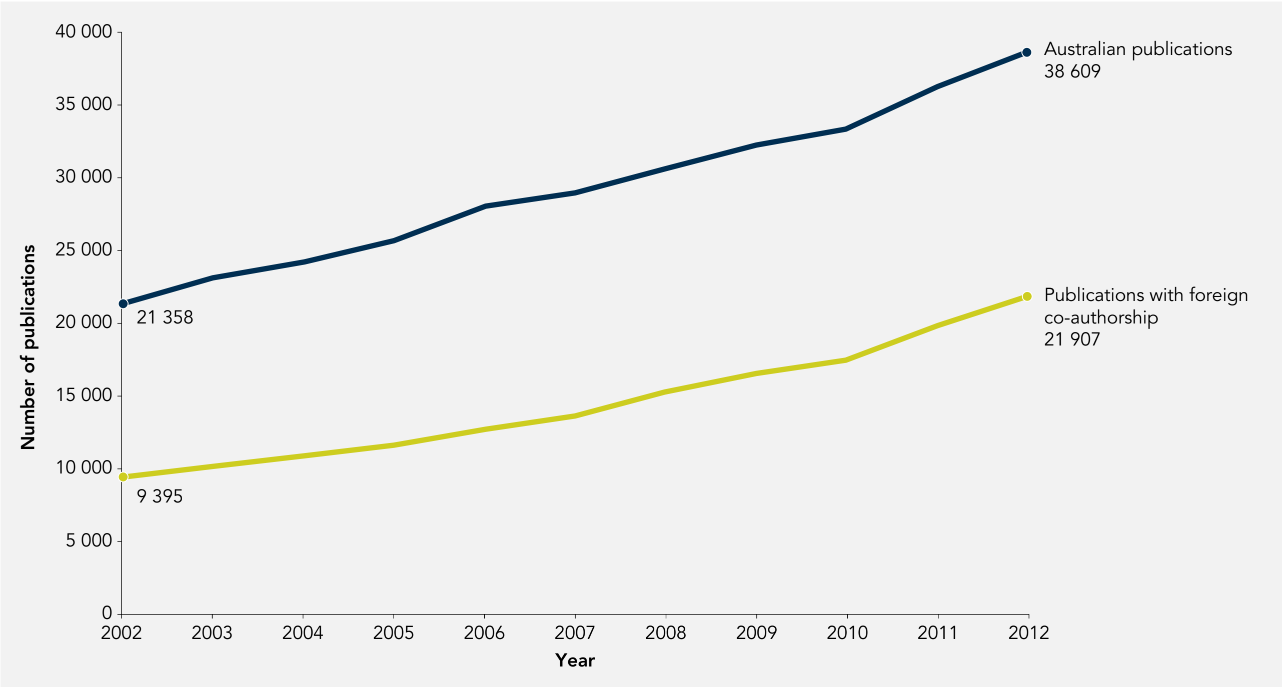
Year	Per cent
2002	45
2003	44
2004	45
2005	46
2006	46
2007	48
2008	50
2009	51
2010	53
2011	55
2012	57

Notes: Total and internationally collaborative publication counts are Web of Science documents classified as article, note or review, by year of publication and assigned to an Australian institution based on the institutional address(es) listed in the publication.

STEM fields were selected using Australia ERA 2012 ERA FoR Level 1 categories mathematical sciences, physical sciences, chemical sciences, earth sciences, environmental sciences, biological sciences, agricultural and veterinary sciences, information and computing sciences, engineering, and technology. Medical and health science excluded.

Source: InCites, Thomson Reuters (2012). Global Comparisons Dataset, Compare Subject Areas in Institution (Australia Totals), 2002–2012. Report created 26 February 2014; data processed 3 July 2013. Data from Web of Science.

Figure 6-1 Australian STEM publications: total and those with international co-authorship, 2002 to 2012



Notes: Publication counts are Web of Science documents classified as article, note or review (proceedings papers are excluded unless they are also classified as articles in Web of Science). Documents are classified by year of publication and are assigned to an Australian institution based on the institutional address(es) listed in the publication.
STEM fields were selected using Australia ERA 2012 FoR Level 1 categories mathematical sciences, physical sciences, chemical sciences, earth sciences, environmental sciences, biological sciences, agricultural and veterinary sciences, information and computing sciences, engineering, and technology. Medical and health science excluded.

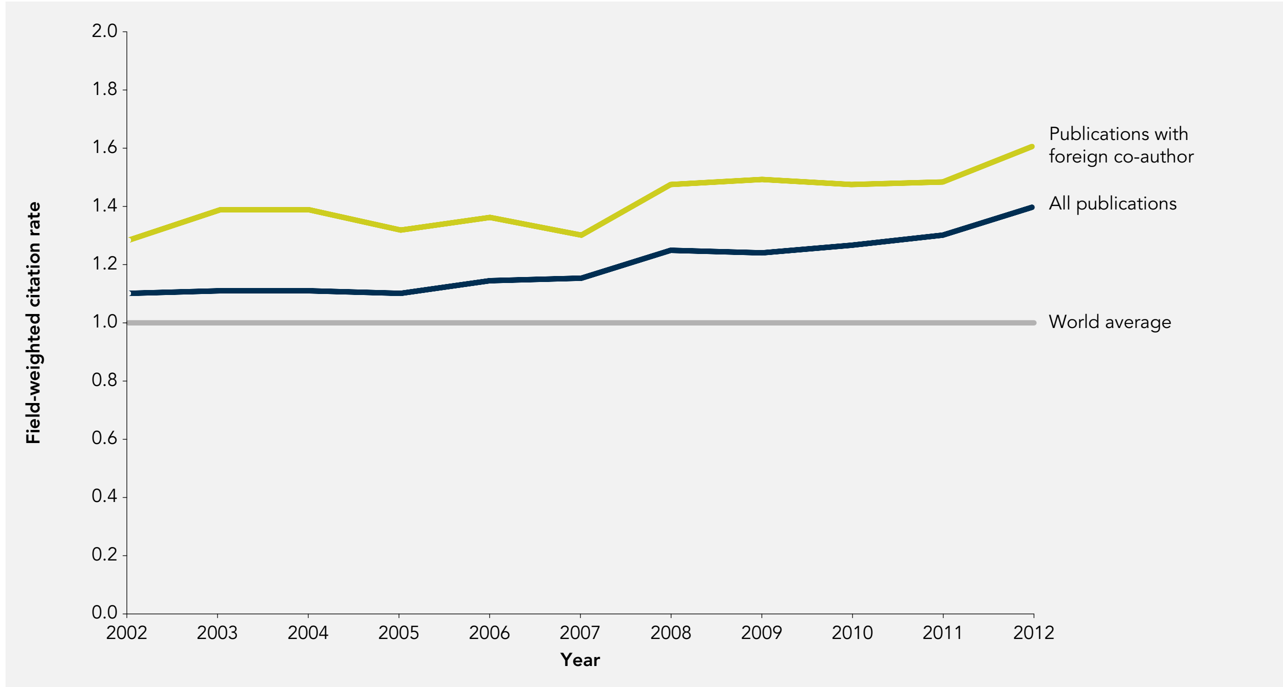
Source: InCites, Thomson Reuters (2012). Global Comparisons Dataset, Compare Subject Areas in Institution (Australia Totals), 2002–2012. Report created 26 February 2014; data processed 3 July 2013. Data from Web of Science.

6.5.2 International co-authorship and citation rates for Australia's STEM publications

Relative to the world average, field-weighted citations for all Australian STEM publications have increased from 1.1 in 2002 to 1.4 in 2012 (see Figure 6-2). In this chapter international research collaboration is assessed by analysing the subset of publications that are co-authored by researchers affiliated with an Australian institution and an international institution. The citation rate for Australian STEM publications with international co-authorship has risen from 1.3 in 2002 to 1.6 in 2012 and has been consistently higher than that for total STEM publications.

While the correlation between international collaboration and the citation rate is clear, it is difficult to determine whether this is a causative relationship. It is difficult to distinguish the 'scale' effect from the 'international' effect: higher citation performance could be largely due to 'big science' projects making use of unique cutting-edge research facilities (for example, the CERN Large Hadron Collider) rather than to international collaboration per se (Mark Matthews, ANU, pers. comm., 21 May 2014).

Figure 6-2 Field-weighted citation rate for all Australian STEM publications and those with international co-authorship, 2002 to 2012



Notes: Citation rates (field-weighted) are based on Web of Science publications classified as article, note or review by year of publication and assigned to an Australian institution based on the institutional address(es) listed in the publication.
STEM fields were selected using Australia ERA 2012 ERA FoR Level 1 categories mathematical sciences, physical sciences, chemical sciences, earth sciences, environmental sciences, biological sciences, agricultural and veterinary sciences, information and computing sciences, engineering, and technology. Medical and health science excluded.

Source: InCites, Thomson Reuters (2012). Global Comparisons Dataset, Compare Subject Areas in Institution (Australia Totals), 2002–2012. Report created 26 February 2014; data processed 3 July 2013. Data from Web of Science.

6.5.3 International co-authorship in Australia compared with other countries

From 2002 to 2012 an average of 50 per cent of Australia's STEM publications were produced with an international co-author (see Figure 6-3). The countries placed to the left of Australia in Figure 6-3 produced a greater proportion of their total STEM publications with international co-authors; those to the right had a smaller proportion.

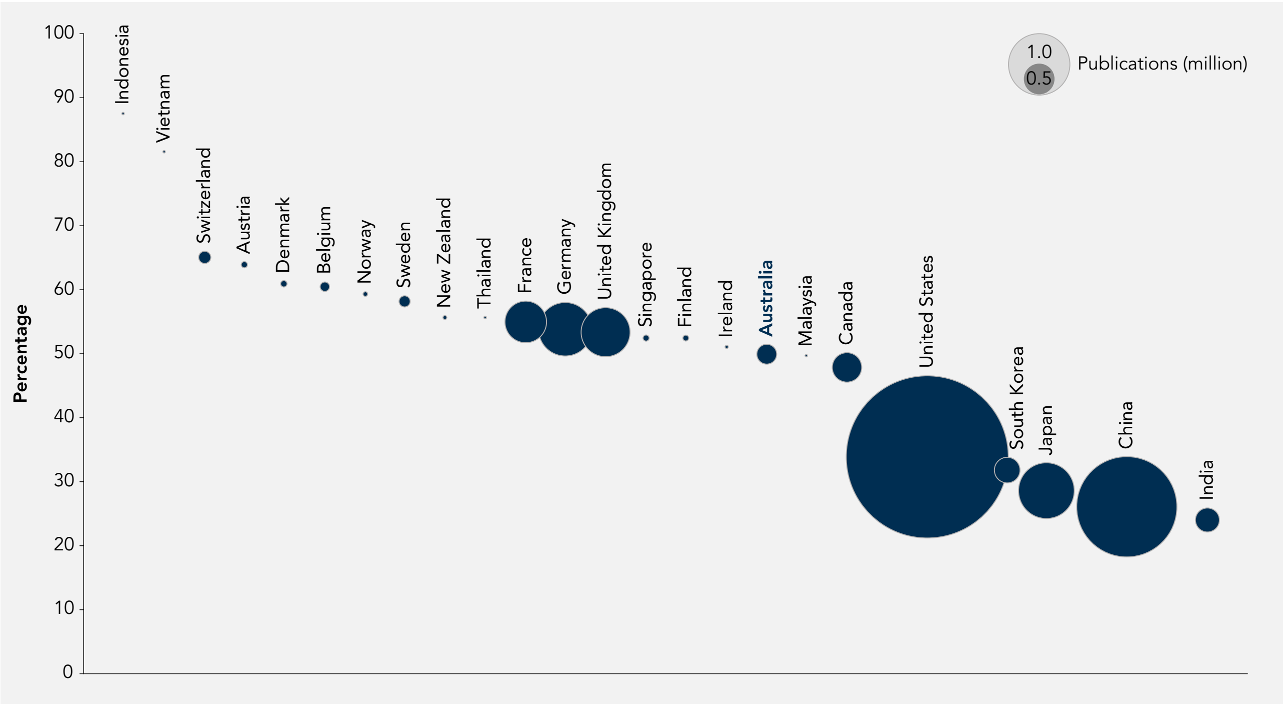
Compared with Australia, all the European comparator countries have a greater proportion of their total STEM publications with an international co-author. This is possibly a result of the countries' geographical proximity, facilitating cross-border collaboration, and also programs that encourage international, institutional and individual research collaboration such as the EU Framework Programme for Research and Innovation (European Commission 2014). The international shares of total STEM publications for the United Kingdom, Germany and France are not much higher than that for Australia (53, 54 and 55 per cent respectively), but those countries have a greater number of publications (indicated by larger circles in Figure 6-3).

Indonesia and Vietnam rely on international co-authorship for the bulk of their STEM publications. Their share of total STEM publications with international co-authorship exceeds 80 per cent. Each of these countries has a smaller number of total STEM publications than Australia.

Of the countries analysed here, Malaysia, Canada, the United States, South Korea, Japan, China and India have a lower share of internationally co-authored publications compared with Australia.

The United States and China have the largest total numbers of collaborative publications, but their shares of total STEM publications that are internationally co-authored are lower than that for Australia. One argument for this is that these

Figure 6-3 Proportion and number of internationally co-authored STEM publications, 2002 to 2012



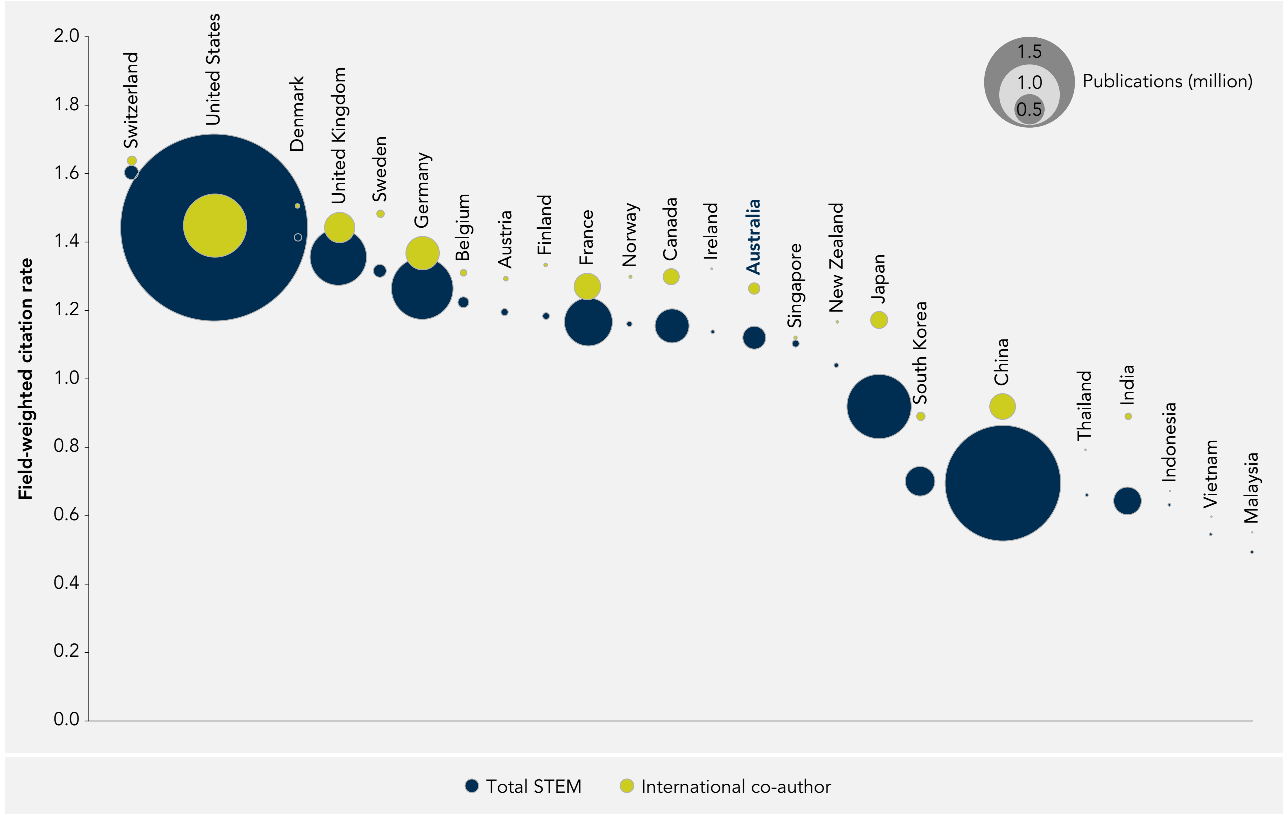
Notes: Total and internationally collaborative publication counts are Web of Science documents classified as article, note or review by year of publication and assigned to an Australian institution based on the institutional address(es) listed in the publication.
STEM fields were selected using Australia ERA 2012 ERA FoR Level 1 categories mathematical sciences, physical sciences, chemical sciences, earth sciences, environmental sciences, biological sciences, agricultural and veterinary sciences, information and computing sciences, engineering, and technology. Medical and health science excluded.

Source: InCites, Thomson Reuters (2012). Global Comparisons Dataset, Compare Subject Areas in Institution (Australia Totals), 2002–2012. Report created 10 March 2014; data processed 3 July 2013. Data from Web of Science.

Table 6-2 Percentage difference between field-weighted citation rates of total STEM publications and the internationally co-authored subset, 2002 to 2012

	Citation rate		
Country	Total	Foreign co-author	Diff. (%)
India	0.64	0.89	39
China	0.70	0.92	33
Japan	0.92	1.17	27
South Korea	0.70	0.89	27
Thailand	0.66	0.79	20
Ireland	1.14	1.32	16
Finland	1.18	1.33	13
Australia	1.12	1.27	13
Sweden	1.32	1.48	12
Canada	1.16	1.30	12
New Zealand	1.04	1.17	12
Norway	1.16	1.30	12
Malaysia	0.50	0.55	12
Vietnam	0.54	0.59	10
France	1.17	1.28	9
Germany	1.27	1.37	8
Austria	1.19	1.29	8
Belgium	1.23	1.31	7
Indonesia	0.63	0.67	7
Denmark	1.42	1.57	6
United Kingdom	1.36	1.44	6
Switzerland	1.60	1.64	2
Singapore	1.10	1.12	1
United States	1.44	1.45	0

Figure 6-4 Field-weighted citation rates for STEM publications with or without international co-authorship, 2002 to 2012



Notes: Total and internationally collaborative publication counts are Web of Science documents classified as article, note or review by year of publication and assigned to an Australian institution based on the institutional address(es) listed in the publication.
STEM fields were selected using Australia ERA 2012 ERA FoR Level 1 categories mathematical sciences, physical sciences, chemical sciences, earth sciences, environmental sciences, biological sciences, agricultural and veterinary sciences, information and computing sciences, engineering, and technology. Medical and health science excluded.

Source: InCites, Thomson Reuters (2012). Global Comparisons Dataset, Compare Subject Areas in Institutions (Australia Totals), 2002–2012. Report created 10 March 2014; data processed 3 July 2013. Data from Web of Science.

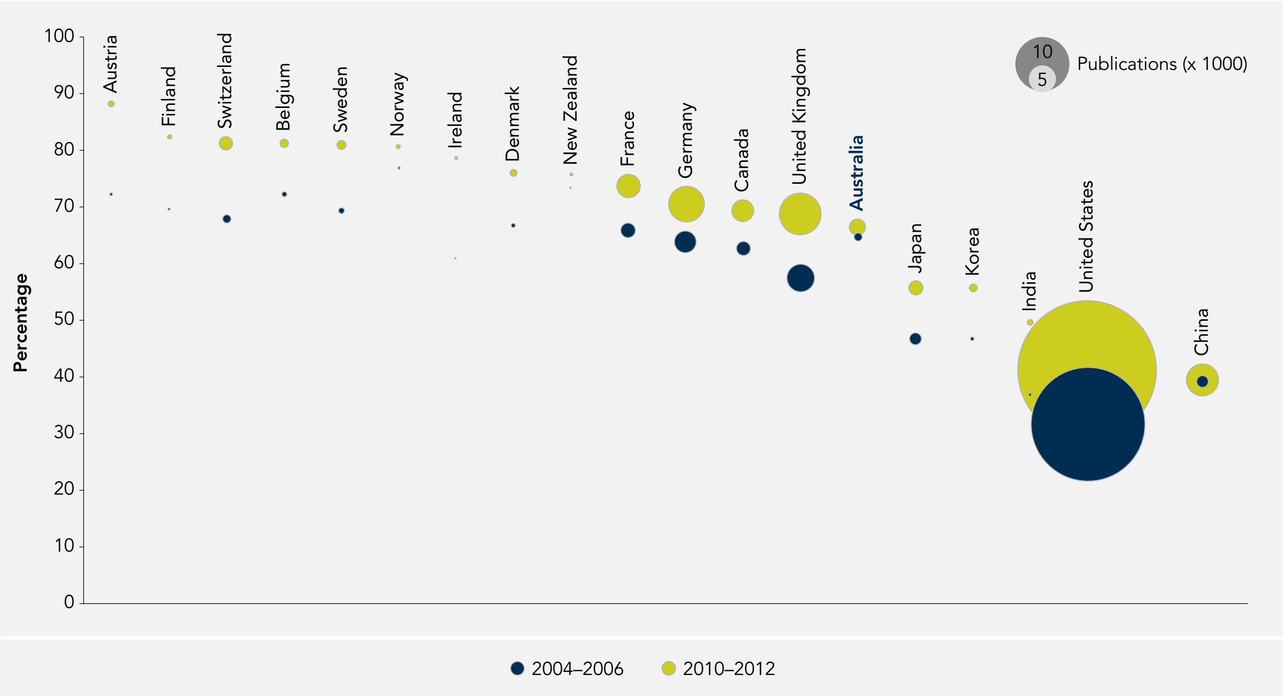
countries do not need to collaborate with international partners simply because of the scale of their domestic research capability. The National Science Foundation (2014) has reported that from 2000 to 2012 the share of domestically co-authored United States publications increased from 21 to 41 per cent.

6.5.4 The difference between average citation rates for all STEM publications and the internationally co-authored subset

Co-authorship with international partners is positively associated with an increase in citation rates (averaged for the period 2002 to 2012) for most of the countries examined. Apart from the United States, the subset of internationally co-authored STEM publications was consistently cited more than the total STEM publications for any country (see Figure 6-4 and Table 6-2). One interpretation of this is that international collaboration is a feature of more frequently cited work. The cause and effect relationship is unclear, but some highly cited research certainly uses a collaborative approach.

The impact of international collaboration on citation rates is not uniform for the countries analysed. Australia's collaborative publications are cited at a rate 13 per cent higher than the average for all STEM publications. This is around the median increase for all the comparator countries (see Table 6-2). Publications from India, China, Japan, South Korea and Thailand benefit most from international collaboration: their internationally co-authored publications received citation rates over

Figure 6-5 Proportion of internationally co-authored publications in the top 1 per cent of citations in natural science and engineering, 2004 to 2006 and 2010 to 2012



Notes: Counts refer to natural science and engineering publications with international co-authorship.

Source: Department of Industry special data request from Thomson Reuters (2012).

25 per cent higher than their total STEM publications in 2002 to 2012. By contrast, the United States does not achieve higher citation rates for its subset of internationally collaborative publications.

6.5.5 Proportion of top 1 per cent of citations in natural science and engineering with international co-authorship

As shown in Figure 3-1, from 2010 to 2012 Australia had a greater share of the world's highly cited publications (top 1 per cent) in natural science and engineering than many of the European comparator countries. This observation raises several questions:

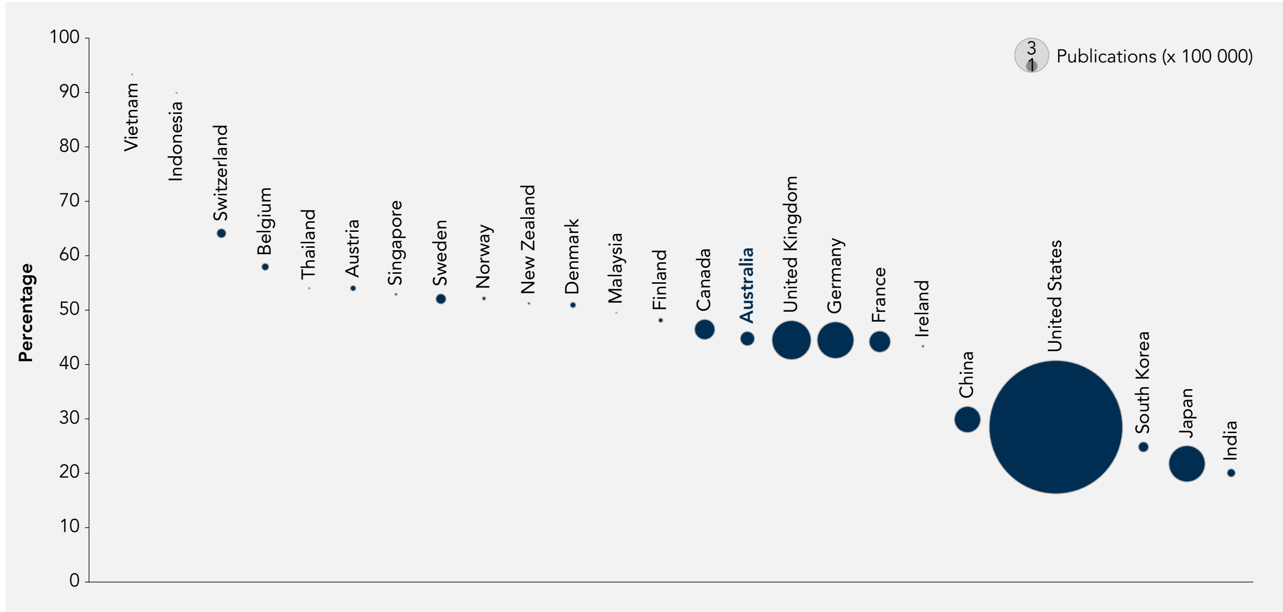
- How important was international collaboration in achieving this?
- Has the influence of international co-authorship on high citation rates remained consistent over time?
- Is international collaboration necessary for top-cited research?

International co-authorship is a feature of highly cited publications for Australia and most of the comparator countries. With the exception of the United States, India and China, for all the countries considered more than 50 per cent of their highly cited publications in natural science and engineering published in 2010 to 2012 were produced through international collaboration (see Figure 6-5).

During 2004 to 2006, 65 per cent of Australia's highly cited natural science and engineering publications had an international co-author; the proportion was 66 per cent in 2010 to 2012—the smallest increase among the comparator countries. By contrast, the United Kingdom's share of highly cited natural science and engineering publications with international co-authorship rose from 57 to 69 per cent, that of the United States from 32 to 41 per cent, and that of Japan from 47 to 56 per cent.

The size of the circles in Figure 6-5 shows the number of highly cited publications for each period. A marked trend that is evident between the two periods is the increase in highly cited publications for all countries.

Figure 6-6 Proportion of internationally co-authored publications in biomedical and clinical health, 2002 to 2012



Notes: Publication counts are Web of Science documents classified as article, note or review, by year of publication and assigned to an Australian institution based on institutional address(es) listed in the publication. BCH fields were selected using Australia ERA 2012 FoR Level 2 categories medical biochemistry and metabolomics, cardiovascular medicine and haematology, clinical sciences, dentistry, immunology, medical microbiology, neurosciences, oncology and carcinogenesis, ophthalmology and optometry, paediatrics and reproductive medicine, pharmacology and pharmaceutical sciences, and medical physiology.

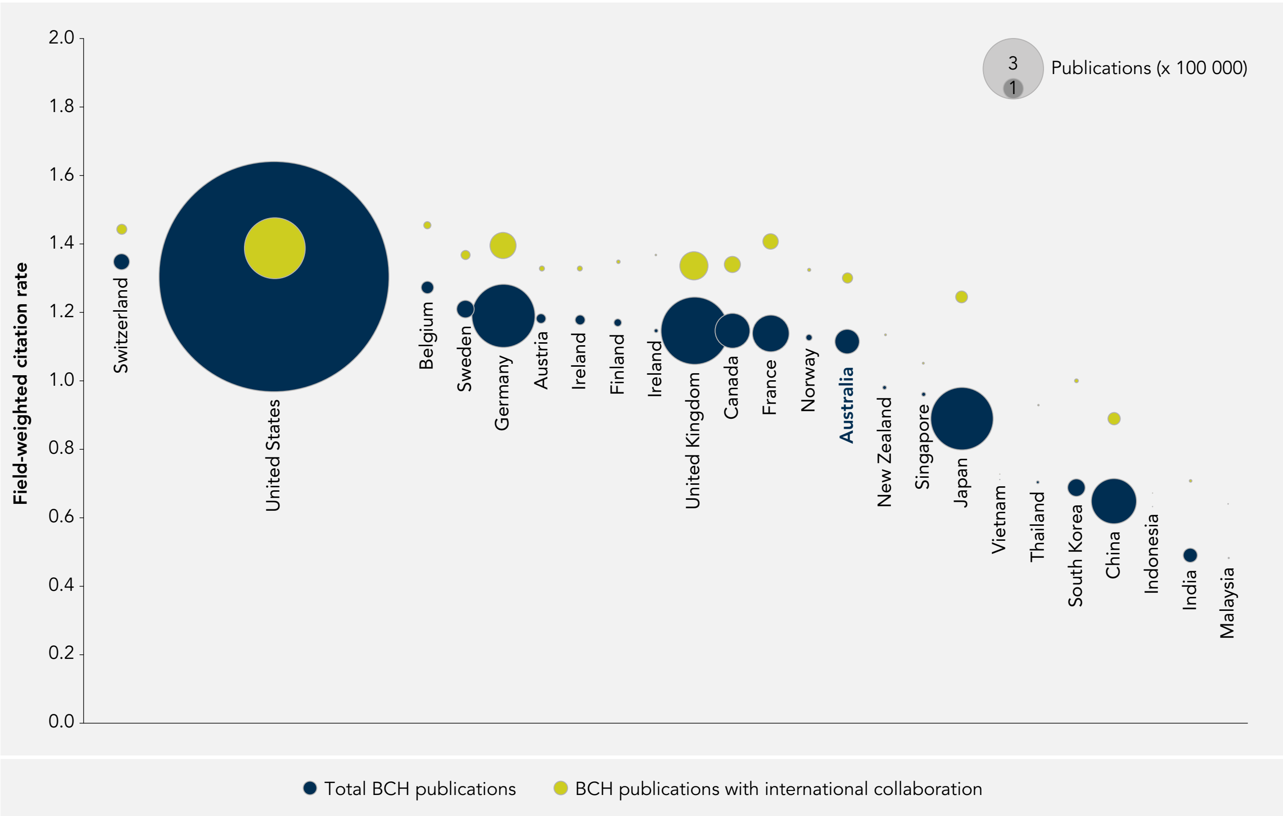
Source: InCites, Thomson Reuters (2012). Global Comparisons Dataset, Compare Subject Areas in Institutions (Australia Totals), 2002–2012. Report created 10 and 20 March 2014; data processed 3 July 2013. Data from Web of Science.

6.5.6 The proportion of biomedical and clinical health publications with international co-authorship

Biomedical and clinical health is the largest field in Australian STEM. In 2002 to 2012 it contributed an average of 37 per cent of total STEM research publications, and it is useful to examine it separately.

The pattern of international collaboration for each nation in BCH (see Figure 6-6) is similar to that for all STEM fields (as shown in Figure 6-3). Compared with Australia, the relatively less populous European nations have a greater proportion of BCH publications that are internationally co-authored. France, the United Kingdom and Germany have a similar level of international collaboration to Australia but a greater overall number of publications. The United States has the greatest number of internationally co-authored publications in BCH but a small proportion of the total BCH publications that are internationally co-authored.

Figure 6-7 Field-weighted citation rates: all biomedical and clinical health publications and the internationally co-authored subset, 2002 to 2012



Notes: Total and internationally collaborative publication counts are Web of Science documents classified as article, note or review by year of publication and assigned to an Australian institution based on the institutional address(es) listed in the publication.
BCH fields were selected using Australia ERA 2012 ERA FoR Level 2 categories medical biochemistry and metabolomics, cardiovascular medicine and haematology, clinical sciences, dentistry, immunology, medical microbiology, neurosciences, oncology and carcinogenesis, ophthalmology and optometry, paediatrics and reproductive medicine, pharmacology and pharmaceutical sciences, and medical physiology.

Source: InCites, Thomson Reuters (2012). Global Comparisons Dataset, Compare Subject Areas in Institutions (Australia Totals), 2002–2012. Report created 20 March 2014; data processed 3 July 2013. Data from Web of Science.

6.5.7 The effect of international co-authorship on citation rates for biomedical and clinical health publications for comparator countries

BCH publications with international co-authorship are consistently more highly cited for all the comparator countries (see Figure 6-7). International collaboration has a more positive influence on BCH publications than on STEM publications in general (compare Table 6-2 and Table 6-3). All the comparator countries have higher average citation rates for internationally co-authored BCH publications. Even the United States, which showed no increase in citation rate associated with international collaboration for all STEM publications, shows a higher rate of citations for internationally co-authored BCH publications.

Table 6-3 Percentage difference between field-weighted citation rates for all BCH publications and the internationally co-authored subset, 2002 to 2012

	Citation rate		
Country	Total	Foreign co-author	Diff. (%)
South Korea	0.69	1.00	45
India	0.49	0.71	44
Japan	0.89	1.24	40
China	0.65	0.89	37
Malaysia	0.48	0.64	33
Thailand	0.71	0.93	32
France	1.14	1.40	23
Ireland	1.15	1.37	19
Norway	1.12	1.32	18
Germany	1.19	1.39	17
Canada	1.15	1.34	17
Australia	1.11	1.30	17

	Citation rate		
Country	Total	Foreign co-author	Diff. (%)
United Kingdom	1.15	1.34	16
New Zealand	0.98	1.13	16
Finland	1.17	1.35	15
Belgium	1.27	1.45	14
Sweden	1.21	1.37	13
Austria	1.18	1.33	12
Denmark	1.18	1.33	12
Singapore	0.96	1.05	9
Switzerland	1.35	1.44	7
United States	1.30	1.38	6
Indonesia	0.64	0.67	6
Vietnam	0.71	0.73	2

6.6 CONCLUDING REMARKS

Australia derives value from international collaboration in STEM research. This collaboration is an important component of Australia's highly cited STEM research publications and is linked to considerations of 'foreign policy, trade, industry competitiveness and international cooperation on key global issues' (Matthews et al. 2010).

Australia has moderate levels of international collaboration when compared with the other countries analysed in this report. It does, however, produce a higher proportion of internationally co-authored STEM publications than large countries such as the United States and China, which might benefit from the sheer scale of domestic endeavour rather than international collaboration.

Competition for international partners in STEM is increasing throughout the world. The number of internationally co-authored STEM publications produced by other countries is rising at a rate faster than in Australia.

Other countries are recognising the importance of international collaboration, so it will be important for Australia—as a geographically isolated country, but within the dynamic Asia–Pacific region—to continue attracting international partners in STEM research.

CHAPTER 7

7. THE STEM WORKFORCE

This chapter reviews the characteristics of the Australian STEM research workforce and compares them with those of other countries. In particular, it looks at the following:

- the size of Australia's research workforce—in absolute numbers and as a share of the total workforce
- the perceived supply and availability of STEM-skilled professionals and the extent to which any shortfalls are met temporarily by skilled overseas workers
- Incorporation of STEM-skilled professionals in the workforce—employment of domestic graduates and skilled overseas workers.

7.1 MAIN FINDINGS

- From 1998 to 2008 Australia's research workforce grew in absolute terms, adding almost 30 000 researchers, and in its share of employment, increasing from 7.3 to 8.5 researchers per 1000 in the workforce.
- At 32 per cent, Australia has the lowest proportion of researchers employed in business relative to the comparator countries.
- In Australia the higher education sector employs the largest share of researchers—60 per cent, second only to the United Kingdom among comparator countries.
- The perceived availability of scientists and engineers declined between 2006 and 2013 in Australia, as it did in all comparator countries other than China.
- The number of skilled overseas workers recruited to Australia through Temporary Work (Skilled) visas (subclass 457) in the professional, scientific and technical field increased from 30 in 2008 to 5690 in 2012.

7.2 BACKGROUND

The capacity of a nation's research workforce determines the skills, knowledge and capabilities to generate innovation and promote economic activity (OECD 2011b). Workers with STEM expertise not only advance basic scientific knowledge but also use this knowledge to design and manufacture new goods and services. As the pace of social and technological change increases, these skills will become increasingly important. STEM researchers, therefore, are crucial to Australia's research effort.

7.3 DATA SOURCES

7.3.1 The OECD Main Science and Technology Indicators database

The workforce data used in this chapter were extracted from the OECD's Main Science and Technology Indicators database, MSTI. The database contains 151 main data series selected from the OECD's Scientific and Technological Indicators database for 30 OECD member countries and nine non-member countries. It provides a set of indicators that reflect the level and structure of the research effort in the field of science and technology from 1981 onwards.

Research workforce data have not been collected in Australia since 2008. To provide information about the development of the Australian research workforce, data from 1998 to 2008 are compared with data from comparator countries for the same period. These data include all researchers, including those in social science and the humanities. It would be preferable to compare data on the STEM research workforce only, but it is difficult to determine whether researchers are working in STEM fields because of the varying workforce classification schemes used in comparator countries. As a consequence, and since STEM research constitutes the majority of research in Australia and the world, it is valid to analyse all researchers (Thomson Reuters 2013).

A summary of characteristics of the Australian STEM workforce is at Appendix B.

7.3.2 The World Economic Forum global competitiveness report

The World Economic Forum global competitiveness report assesses the productivity and prosperity of 148 economies. Data on the perceived availability of scientists and engineers were collected in the forum's Executive Opinion Survey, conducted in Australia by the Australian Industry Group. Two editions of the global competitiveness report were consulted, 2006–07 and 2013–14.

7.3.3 The Department of Immigration and Border Protection

The Department of Immigration and Border Protection compiles statistics on holders of Temporary Work (Skilled) visas (subclass 457) from the visa application and grant process. The applicant and their business sponsor provide a range of information to enable the department to assess the eligibility of the sponsor and the applicant for the visa. The data include information such as the location of the nominated position, the nominated occupation, the nominated base salary, and the country of citizenship for applicants.

7.4 COUNTRIES ANALYSED

As in previous chapters, two groups of benchmarking nations were identified for analysis—countries at stages of development similar to that of Australia and with similar governance systems (the United States, Canada and selected European nations) and selected countries in the Asia–Pacific region.

This chapter generally includes analysis of the European comparator nations (Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Norway, Sweden, Switzerland and the United Kingdom) and comparator nations from our region (China, Japan, New Zealand, Singapore and South Korea). Additionally, data on the perceived availability of scientists and engineers are provided for India, Indonesia, Malaysia, the Philippines, Thailand and Vietnam.

7.5 THE RESEARCH WORKFORCE

7.5.1 Characteristics of the Australian research workforce relative to the research workforce in other countries

A productive research workforce is essential for innovative research and development. By comparing the research workforce over time, we can understand how Australia's research capacity has changed. As an indicator of research capacity, the number of researchers in Australia can be compared with the number in other countries.

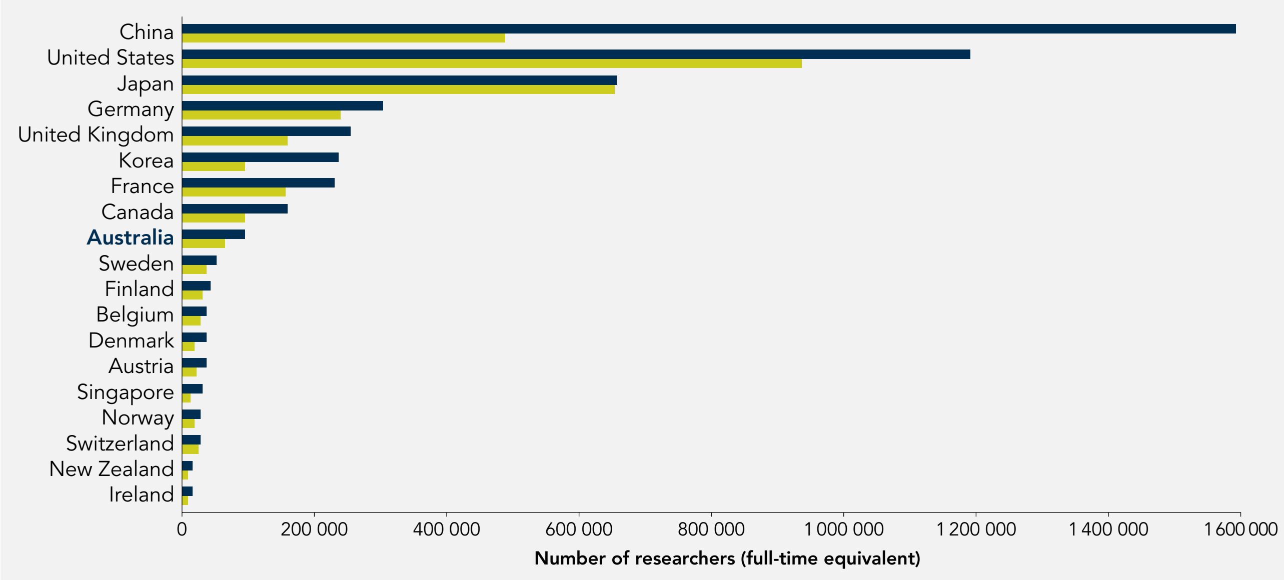
Worldwide, 86 per cent of research publications from 2002 to 2012 were in STEM fields. In Australia the figure was 79 per cent. Since there is no standard indicator associated with STEM researchers specifically, all researchers are analysed instead. As noted, in view of the predominance of STEM research in Australia and the world, it is reasonable to assess total researchers as representative of STEM researchers.

Australia's research workforce grew from 62 865 in 1998 to 92 649 in 2008 (see Figure 7-1), an increase of 47 per cent. This is a higher rate of growth than in the United States (27 per cent), France (46 per cent) and Germany (27 per cent)—see Table 7-1. The Chinese research workforce grew the most during the period, from 485 500 to 1 592 420, or by 228 per cent. In absolute terms China now outstrips the United States, which previously had the largest research workforce.

7.5.2 Links between the research workforce and the number of research publications

The rapid growth in China's research workforce from 2002 to 2012 corresponds with the growth in China's STEM publications (see Chapter 2). The citation rates for China's aggregate publication output were, however, below the world average during the period (Figure 2-3). The United States had the second largest workforce in 2008 and produced the second largest number of STEM publications between 2002 and 2012. All the US research fields received citation rates above the EU15 (Figure 2-2).

Figure 7-1 Research workforce, 1998 and 2008



Notes: Data on the research workforce have not been available for Australia since 2008. For Denmark, Norway and Sweden figures for 2007 are shown since there are no data available for 2008. Similarly, New Zealand data are from 1997 and 2007, while 1998 data for Switzerland are calculated as an average of 1996 and 2000.

Source: OECD, MSTI, January 2014.

Table 7-1 Increase in research workforce, 1998 to 2008

Country	Increase (%)
China	228
South Korea	155
Singapore	144
Denmark (1997, 2008)	104
Ireland	88
Austria	84
Canada	65
United Kingdom	60
Australia	47

Country	Increase (%)
Norway (1997, 2008)	46
France	46
Sweden (1997, 2008)	36
Finland	34
Belgium	33
Germany	27
United States	27
Japan	1

Denmark has a small total research workforce, 35 702 in 2008, produces a similar number of publications to other European nations but has a very high citation rate, with all fields above the EU15 rate. By contrast, Australia has a larger research workforce than Denmark, 92 649 in 2008, and a larger number of publications but only four fields with citations rates above the EU15.

In brief, the size of a research workforce influences research output, although it does not necessarily relate to the influence of the research publications (as measured by citation rates).

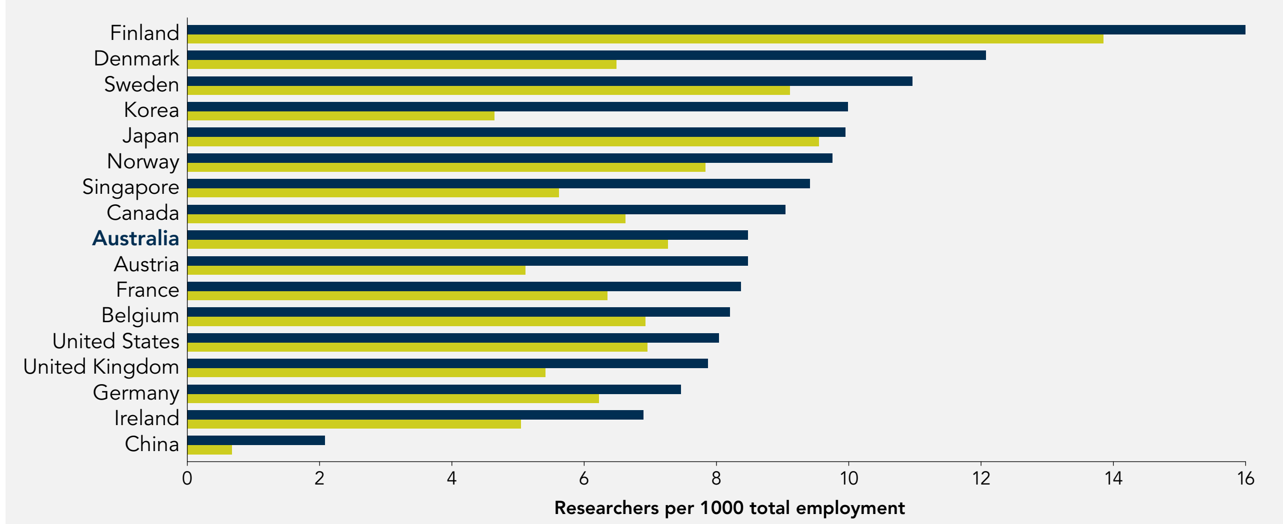
7.5.3 How does the share of Australian researchers in the workforce compare with the share in other countries?

The absolute number of researchers in a country provides an indication of the country's research capacity. Normalising the number of researchers to the population, and to the labour force, can show the relative emphasis placed on research within a country and in its labour market.

In 2008 the share of researchers in the Australian workforce (8.5 per 1000 workers) was at the midpoint (nine out of 18) among the comparator countries—greater than in China, Canada, the United Kingdom, Germany and France but less than in all the smaller European nations considered (see Figure 7-2). As noted, there are no data on the Australian research workforce since 2008.

Between 1998 and 2008 the share of researchers in the workforce increased at different rates in the countries analysed (see Table 7-2). Nearly all the comparator countries had a higher growth rate than Australia during this period.

Figure 7-2 Researchers as a share of total workforce, 1998 and 2008



Notes: Data on the research workforce have not been available for Australia since 2008. For Denmark, Norway and Sweden, figures for 2007 are shown since there are no data available for 2008.

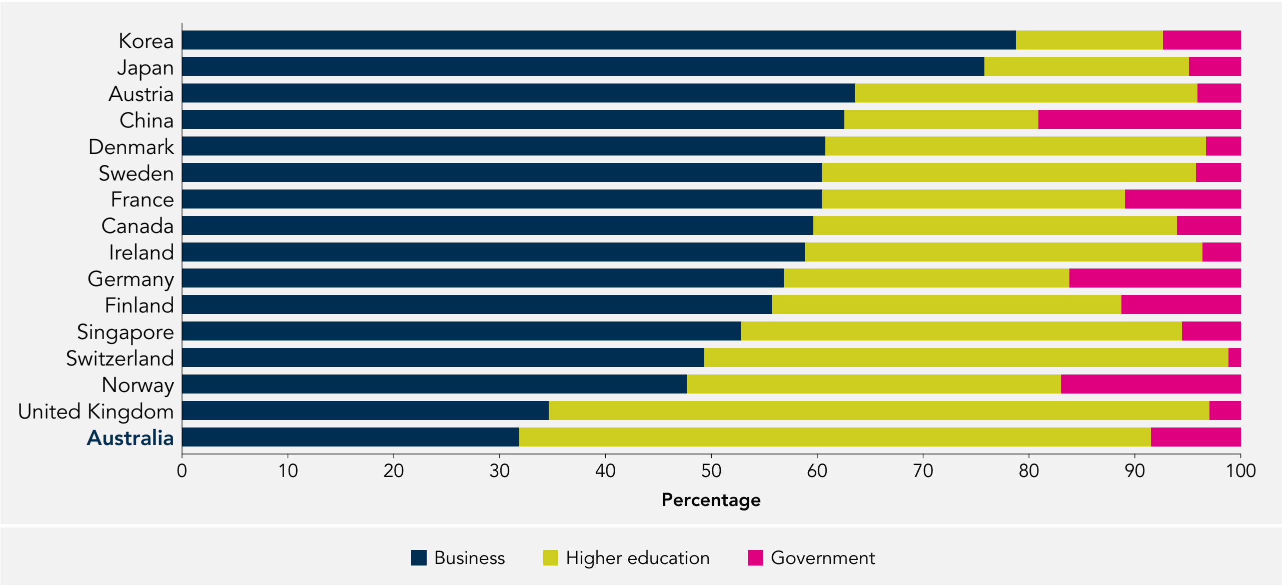
Source: OECD, MSTI, January 2014.

Table 7-2 Increase in researchers as a share of the workforce, 1998 to 2008

Country	Increase (%)
China	207
Korea	116
Denmark	85
Singapore	67
Austria	65
United Kingdom	45
Canada	37
Ireland	36

Country	Increase (%)
France	31
Norway	24
Sweden	21
Germany	20
Belgium	19
Australia	17
Finland	16
United States	15

Figure 7-3 Employment of researchers, by sector, 2011



Notes: Australian research workforce data were last collected in 2008, but data were still reported for the government, business and higher education sectors beyond this (2011). Researchers working outside business, higher education and government are not included in the data. In 2008 these sectors accounted for 96 per cent of researchers in Australia.

Source: OECD, MSTI, January 2014.

7.5.4 How does the distribution of researchers across sectors of the Australian economy compare with the distribution in other countries?

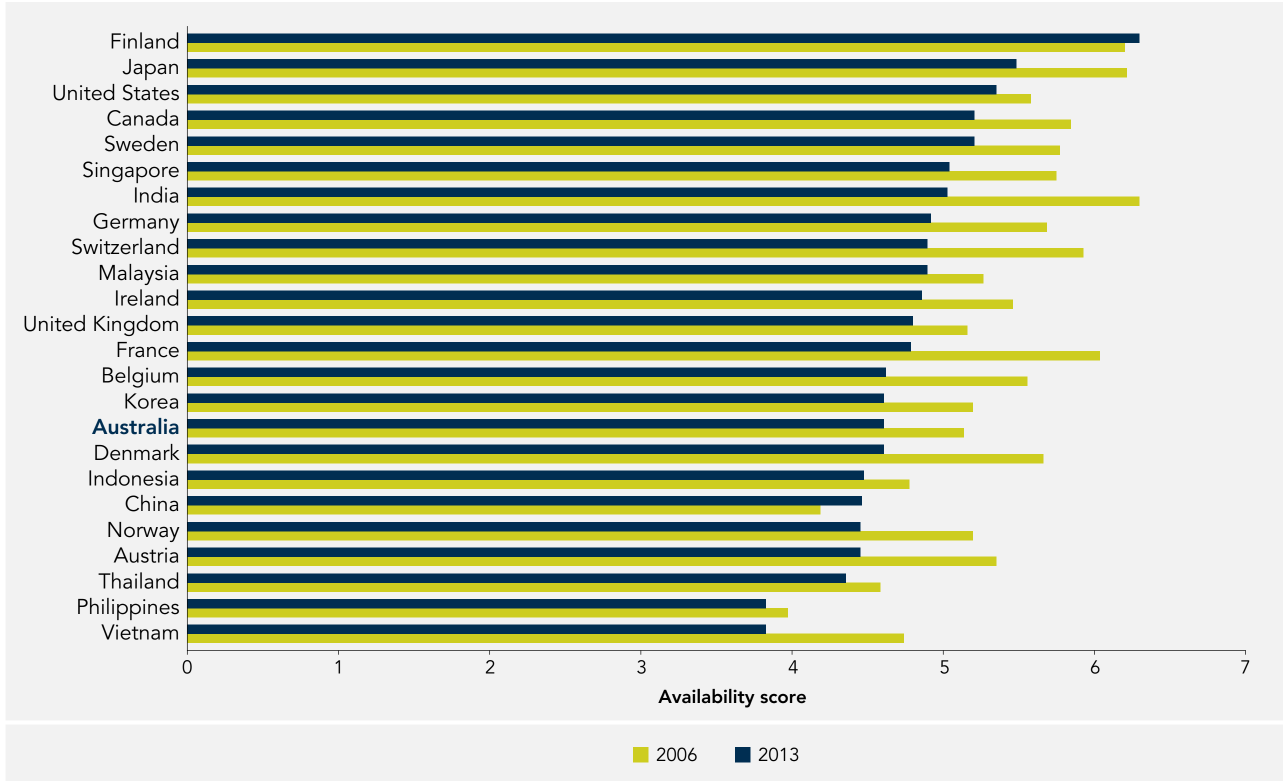
Australia has a relatively small proportion of its research workforce employed in the business sector, at 32 per cent in 2008 (see Figure 7-3). Further, this proportion is one of the lowest in the OECD (Department of Industry 2013).

The sectoral profile of researchers in the United Kingdom is similar to that in Australia. In the United Kingdom encouraging closer relations between universities and business is now an important policy goal, the newly created Catapult Centres aiming to bridge the gap between businesses and universities (OECD 2012).

The distribution of researchers in the other European comparator countries is fairly consistent: on average, 56 per cent of researchers are employed by business (range 48–63 per cent), 35 per cent in higher education (range 27–49) and the remaining 9 per cent in government (range 1–17).

Korea and Japan stand apart, with a large majority of researchers—79 and 76 per cent respectively—employed in the business sector. R&D in both countries is conducted mainly by large manufacturing conglomerates, and public research systems are also strongly oriented towards applied and experimental R&D (OECD 2012).

Figure 7-4 Perceived availability of scientists and engineers, 2006 and 2013



Notes: Potential respondents were selected from main sectors of the economy (agriculture, manufacturing industry, non-manufacturing industry, and services). Although the sample size was small (57 business leaders for Australia), the results have remained consistent across the annual run of reports.

Source: World Economic Forum global competitiveness report, 2006–07 and 2013–14 editions.

7.5.5 Australian employers' perception of the availability of scientists and engineers

As part of the World Economic Forum's global competitiveness report the Executive Opinion Survey posed the question, 'In your country, to what extent are scientists and engineers available? [1 = not at all; 7 = widely available]'.

The perceived availability of scientists and engineers has declined between 2006 and 2013 in Australia and in all comparator countries other than China and Finland (see Figure 7-4). Australia is positioned in the lower third (16 out of 24) of the cohort. This decline suggests a growing shortage of professionals with science and engineering skills.

It is noteworthy that few Australian businesses responded to this survey. [3]

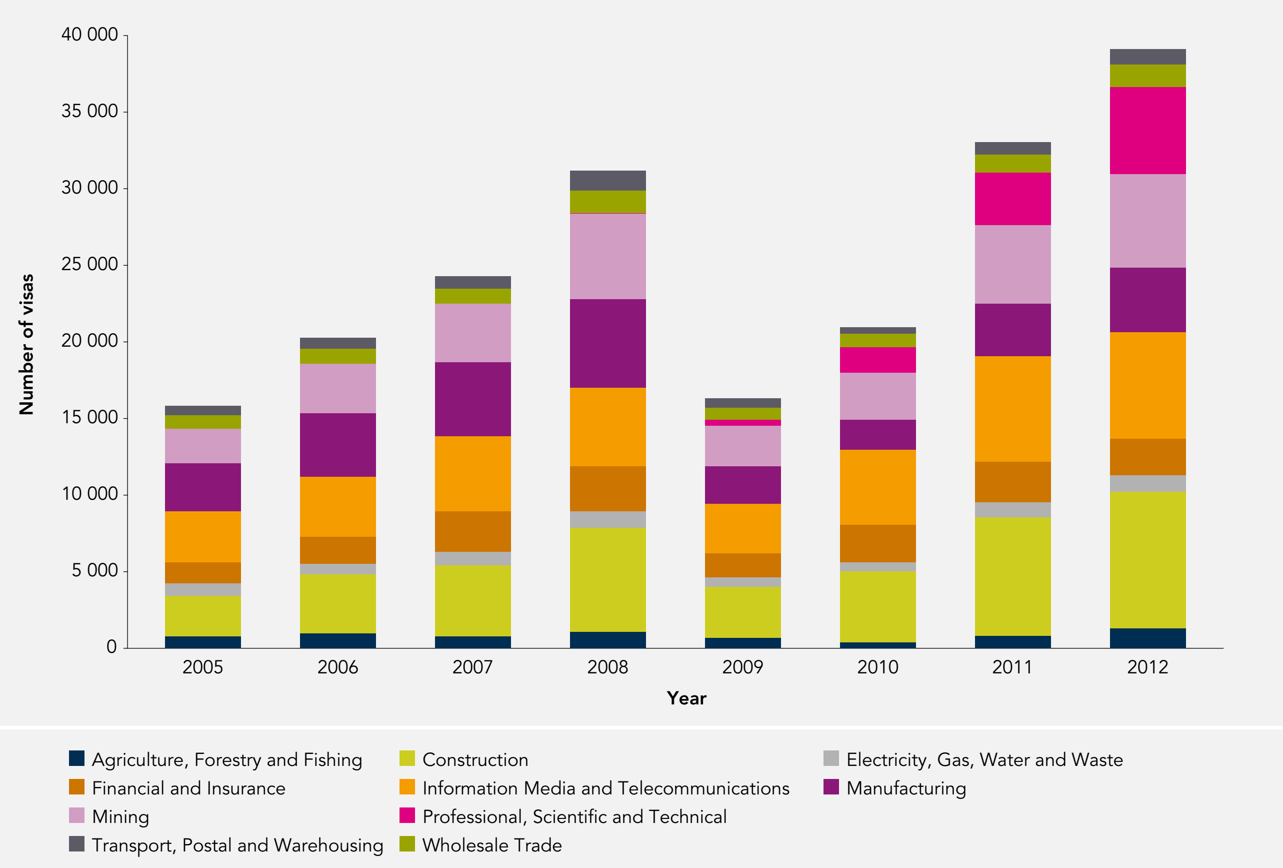
7.5.6 Trends in business-sponsored temporary work visas, 2005 to 2012

Businesses can rely on skilled migration to redress skills shortages that cannot be resolved by the domestic market.

A Temporary Work (Skilled) visa (subclass 457) allows an overseas skilled worker sponsored by an approved business to work in Australia for up to four years. A business can sponsor someone for a subclass 457 visa if they cannot find an appropriately skilled applicant who is an Australian citizen or permanent resident (Department of Immigration and Border Protection 2014). Because this visa class is sponsored by businesses, it can reflect a real and genuine need on the part of Australian businesses to employ workers who have skills that are not available in the Australian domestic market.

3 Ranking the response rate for all 149 countries that took part in the World Economic Forum Business Survey, Australia's 57 responses come in at 117.

Figure 7-5 Temporary Work (Skilled) visas (subclass 457) issued, major STEM-related Australian industries, 2005 to 2012



Notes: Figures rounded to the nearest 10. The Australian and New Zealand Standard Classification of Occupations (ANZSCO) was introduced by the Department of Immigration and Border Control on 1 July 2010. Applications lodged before that date using the Australian Standard Classification of Occupations (2nd edition) have been converted to an ANZSCO code using standard DIBP mapping approved by the Australian Bureau of Statistics.

Source: Department of Immigration and Citizenship (2013).

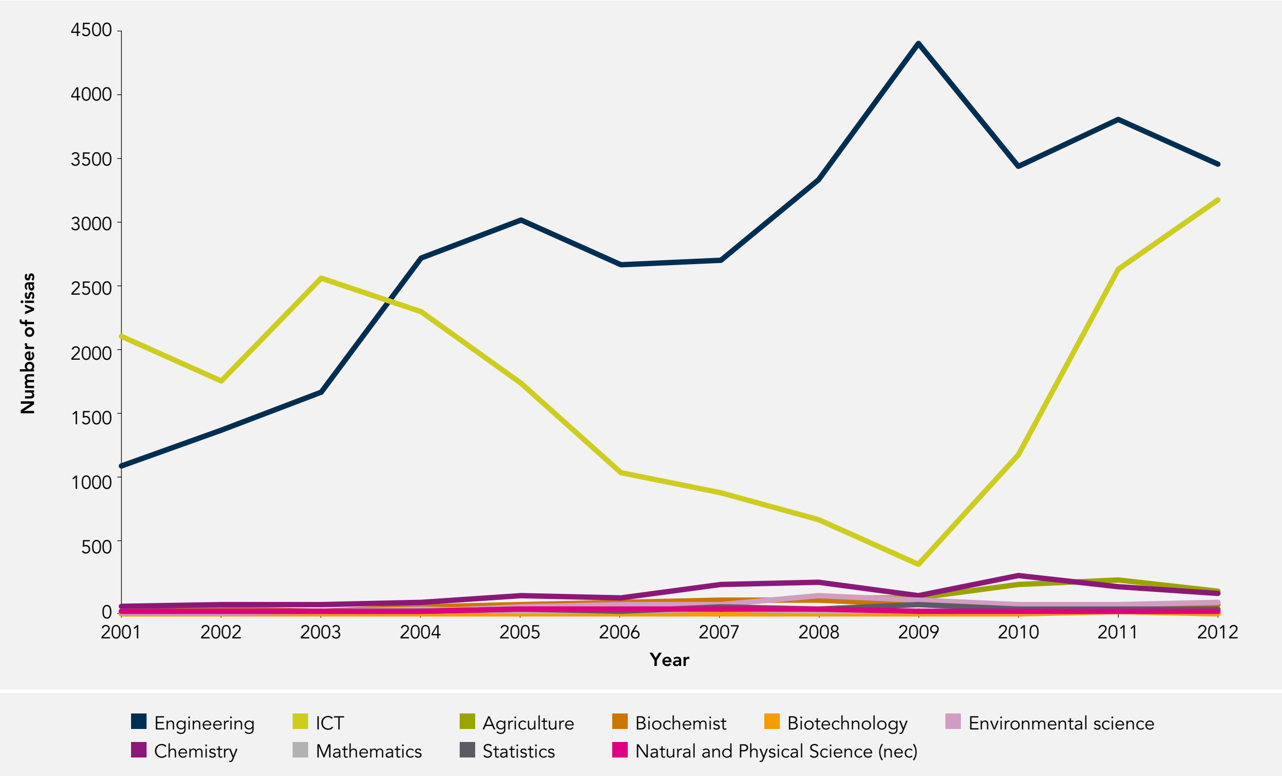
There was an overall increase in the number of STEM-related temporary visas issued in Australia between 2005 (15 870) and 2012 (39 120). The growth was not consistent, however, with a pronounced dip in numbers after 2008, from 28 450 down to 14 980 in 2009 (see Figure 7-5). The dip in numbers was apparent across all the industry categories analysed. Ten industry categories with businesses that support high levels of R&D were selected for this analysis (see Figure 5-9).

Overall, the two industries that supported the highest number of skilled workers were construction, with 42 640 temporary visas issued between 2005 and 2012, and information, media and telecommunications, with 39 140.

No temporary work visas were issued in the professional, scientific and technical area before 2009, but an annual step-wise increase resulted in 5690 being issued in 2012.

Sponsorship of temporary workers has remained fairly stable in the agriculture, financial and insurance (a mathematics-dependent industry field), wholesale trade, and electricity, gas and water industries, each with about 500 to 1000 temporary visas a year.

Figure 7-6 Subclass 457 visas issued, selected skill streams, 2001 to 2012



Notes: Engineering includes aeronautical engineers, aircraft maintenance engineers (avionics), aircraft maintenance engineers (mechanical), aircraft maintenance engineers (structures), biomedical engineers, chemical engineers, civil engineers, civil engineering draftspersons, civil engineering technicians, computer network and systems engineers, electronics engineers, engineering managers, engineering patternmakers, engineering production workers, engineering technologists, environmental engineers, and engineering professionals that are not elsewhere classified.

Agriculture includes agricultural consultants, agricultural engineers, agricultural scientists and agricultural technicians.

ICT includes analyst programmers, database administrators, network administrators, network analysts, ICT business analysts, ICT business development managers, ICT customer support officers, ICT project managers, ICT quality assurance engineers, ICT security specialists, ICT support engineers, ICT systems test engineers, ICT trainer and ICT support technicians, and ICT support, test engineers, and managers that are not elsewhere classified.

Chemistry includes chemists and chemistry technicians.

Environmental science includes environmental research scientists and environmental scientists that are not elsewhere classified.

Natural and physical science includes those natural and physical scientists that are not elsewhere classified.

Source: Department of Immigration and Citizenship (2013).

From 2001 to 2012 most subclass 457 visas were issued for employment in engineering and information and computing technology (see Figure 7-6).

The growth in the number of temporary visas granted in the engineering stream is due mainly to high rates of employment opportunities for civil and electronics engineers. Shortages of professional engineers in civil, electrical, mining, petroleum and mechanical engineering have been persistent for many years, although recent Department of Employment data show the labour market has eased (Department of Employment 2014). The Australian Workforce and Productivity Agency's consultations with employers suggest that, even though labour market conditions have eased (see Table 7-3), 'employers continue to experience difficulty in filling engineering-related occupations' (Australian Workforce and Productivity Agency 2014). This may be a result of engineering firms requiring employees with several years' experience and sector-specific skills.

Table 7-3 Migration program outcomes for skilled stream, by Australian and New Zealand Standard Classification of Occupations: engineers, 2001 to 2012

Type of engineer	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Aeronautical	18	15	25	50	46	61	34	58	11	76	74	55
Aircraft maintenance (avionics)	13	27	11	44	52	28	21	54	75	34	30	17
Aircraft maintenance (mechanical)	72	40	48	61	61	65	92	122	191	65	82	44
Aircraft maintenance (structures)	15	11	13	45	41	40	16	15	26	15	13	8
Biomedical	<5	6	<5	6	17	17	16	18	10	68	54	52
Chemical	89	148	131	229	299	358	289	435	524	357	380	231
Civil	265	333	355	447	695	809	921	1144	1637	1066	1091	1025
Civil (draftsperson)										38	64	60
Civil (technician)	14	17	33	33	58	51	62	92	107	94	88	58
Computer network and systems										35	133	488
Electronics	107	110	188	345	449	505	598	744	1,408	861	849	582
Manager	18	17	28	57	63	38	64	125	123	118	165	160
Patternmaker											<5	<5
Production worker				<5	<5		<5		<5	<5		<5
Professionals (nec)	333	469	566	909	743	373	281	253	113	174	190	212
Technologist	193	222	320	519	508	357	335	291	177	414	538	407
Environmental										33	60	79
Total	1137	1415	1718	2745	3032	2702	2729	3351	4402	3448	3811	3478

Notes: Data on grants of permanent visas are Migration Program Outcomes, which are the number of visas granted net of Business Skills visas cancelled under s. 134 of the Migration Act 1958 and net of places taken by partner visa holders who do not subsequently obtain permanent visas due to refusal or withdrawal. Small cell sizes with values between 1 and 4 are reported as <5. Occupation detail only available for principals within the skill stream. The Australian and New Zealand Standard Classification of Occupations was introduced by the (now) Department of Immigration and Border Control on 1 July 2010. Applications lodged before that date using the Australian Standard Classification of Occupations (2nd edition) have been converted to an ANZSCO code using a standard DIBP mapping approved by the ABS.

Source: Department of Immigration and Citizenship (2013).

The high numbers of ICT temporary visas from 2001 to 2003 and from 2009 to 2012 are probably a consequence of domestic shortages of ICT-skilled workers in Australia and the global nature of the ICT workforce. The fall in ICT temporary visas issued after 2003 is probably due to the dotcom crash and the resultant contraction of the ICT sector. This was also reflected in the decline in the number of domestic students enrolling in bachelor-level IT degrees in Australian higher education institutions between 2002 and 2008 (see Chapter 8).

7.6 CONCLUDING REMARKS

The number of researchers in Australia has been growing. Despite this, Australia still has the lowest proportion of researchers in business compared with the other countries analysed—about 32 per cent. Compounding this is the fact that Australia has one of the lowest rates of industry–research collaboration in the OECD (see Chapter 4).

Australia had 8.5 researchers per 1000 in total employment in 2008. No new research workforce data were collected after that date. The gap in information might be significant given that some countries recorded a faster rate of growth in their research workforce compared with Australia before 2008. Countries in the Asia–Pacific region—in particular, China and Korea—have more than doubled the size of their research workforce (since 1998). Globally, surveys show there are fewer scientists and engineers available to employers in every country except China.

There are insufficient data to correlate the supply of trained STEM workers and the associated demand and uptake in the workforce in Australia. An understanding of this relationship would be valuable for workforce policy development.

CHAPTER 8

8. HIGHER EDUCATION

This chapter benchmarks the supply of Australian higher education students and graduates in STEM fields. The current pipeline of STEM students and graduates is benchmarked against previous years and other countries for which data are available. Bachelor's degrees (the typical first degree in Australian higher education) in STEM fields are assessed over time in order to discern trends in the Australian system; this is followed by an analysis of the doctoral cohort, then the international context.

The chapter also looks at the distribution of students between all education fields so as to draw conclusions about the relative emphasis on STEM in comparator countries. Finally, it presents an assessment of funding support for Australian doctoral candidates.

8.1 MAIN FINDINGS

- Overall, domestic student commencing enrolments in bachelor's degrees in STEM fields increased between 2002 and 2012. Science and engineering enrolments grew during the period, while those in information technology and agriculture and environment fell.
- Bachelor's degree completions for the STEM fields show trends similar to those for enrolments.
- The number of commencing research doctorate student enrolments in the STEM fields remained stable between 2002 and 2012.
- The STEM fields accounted for 35 per cent of commencing doctoral students across all fields of education in 2012.

8.2 BACKGROUND

Higher education plays a crucial role in STEM in Australia. Qualification in a STEM field from a higher education institution is the gateway to crucial workforce roles in STEM—from science and mathematics teachers to engineering professionals, from computer programmers to government science advisers, from agronomists to researchers. Without the training, research and development role of the higher education sector, it would be difficult to develop a workforce capable of STEM-based innovation.

8.3 DATA SOURCES AND TERMINOLOGY

Data on domestic student bachelor's degree enrolments and completions were provided by the Australian Government's Department of Education's Higher Education Statistics Data Cube (uCube)[4], which is based on the student and staff data collections. The data could include a small amount of double-counting in the number of undergraduate enrolments and completions in individual STEM fields shown in this report. This is because students can enrol in and then complete more than one STEM degree. Customised data sets on research doctorate degree enrolments and completions were also provided by the Department of Education.

The terminology adopted in this chapter envisages that students enrol in higher education courses that are offered at different levels. Typical course levels are entry-level undergraduate courses such as a bachelor's degree and higher and research-based degrees such as a PhD. When students satisfy the requirements of their course and graduate they are counted as completions.

4 Available at http://www.highereducationstatistics.education.gov.au.

Table 8-1 International Standard Classification of Education fields and the Australian equivalents

ISCED STEM field of education	Australian equivalent field of education
05 Natural sciences, mathematics and statistics	01 Natural and physical sciences
06 Information and communication technologies	02 Information technology
07 Engineering, manufacturing and construction	03 Engineering and related technologies
08 Agriculture, forestry, fisheries and veterinary sciences	05 Agriculture, environmental and related studies

Higher education courses, such as a Bachelor of Science or a PhD, are classified into 12 broad fields of education, according to the course's main subject matter or vocational intent. In this report the STEM fields of interest and their two-digit codes are 01 Natural and Physical Sciences (referred to as science)[5], 02 Information Technology (IT), 03 Engineering and Related Technologies (engineering) and 05 Agriculture, Environmental and Related Studies (agriculture and environment).

Students enrolled in Australian universities are classified as either domestic or international students. Domestic students are largely Australian residents; international students are usually residents of other countries who are studying in Australia on a student visa.

Students are further classified as either commencing or continuing. Commencing students are those enrolled at an institution for the first time in a particular course. Commencing status applies for one calendar year only. Commencing enrolments for most course levels provide an indication of how many students are entering the system at that course level. This can, however, be an overestimate since some students could be counted as commencing in two or more years if they start a degree at one university then change or transfer to another university or course at a later date.

The Australian higher education data used in this chapter cover the years 2002 to 2012 because this is a period when consistent counting methodologies and field classifications were used (Dobson 2012).

International higher education statistics are from the UNESCO Institute of Statistics and cover enrolment and completion data in 2010. UNESCO uses the International Standard Classification of Education (see Table 8-1). While the available data are assembled to produce complete and internationally comparable data sets, initiatives to ensure comparability of frameworks in the European Union have meant that there could be double-counting when comparing enrolments and completions.

The international and domestic data presented here come from different databases that might have different approaches to classifying course levels and fields of education. For this reason the two sets of data are not directly comparable.

8.4 THE 'MELBOURNE MODEL' AND STEM ENROLMENTS

In 2008 the University of Melbourne made changes to the structure of its undergraduate STEM programs (Dobson 2014). Under the new structure the number of separate bachelor's degrees offered by the university was reduced and students who wanted to eventually qualify in a specific vocational field such as engineering or medicine would first need to complete a bachelor's degree in science. Similarly, students who wanted to qualify in architecture would first need to complete a bachelor's degree in agriculture and environment. This new structure was dubbed the 'Melbourne model'. A similar system was introduced at the University of Western Australia in 2012. The effect at Melbourne, and later at UWA, was declines in bachelor's enrolments in engineering, medicine and architecture, with concurrent expansions in science and agriculture and environment.

5 Natural and Physical Sciences includes the narrow fields of mathematics, chemistry, physics, biology, earth sciences, medical science, and 'other', which includes forensic science and pharmacology.

These changes affect only two universities out of dozens in Australia but, because they affect nearly 11 per cent of STEM undergraduates[6], their influence on enrolment trends could be significant. Any associated increases or decreases do not, however, necessarily reflect a change in student interest in particular STEM fields. Nor do they produce an attendant change in the supply of students entering the workforce with particular qualifications: a student at Melbourne who wants to be an engineer will show up as an extra science graduate, but once they complete their tertiary pathway they will enter the workforce as an engineer.

For these reasons bachelor's degree enrolment numbers in this chapter were calculated in two ways. First, data are presented for the entire undergraduate cohort for all universities. A second set of results is then presented, in which the cohort is restricted to exclude students at Melbourne and UWA. This allows trends in student preferences for STEM to be separated from trends resulting from the introduction of the Melbourne model.

8.5 COUNTRIES ANALYSED

As in previous chapters, two groups of nations were identified for analysis—countries at stages of development similar to that of Australia and with similar governance systems (for example, countries in North America and Europe) and countries from the Asia–Pacific region.

Australia was compared with Europe (Austria, Belgium, Denmark, Finland, Germany, Ireland, Norway, Sweden, Switzerland and the United Kingdom), North America (Canada and the United States) and countries from the Asia–Pacific region (New Zealand, Japan and South Korea).

The countries chosen have already been used in this report, and UNESCO's Institute of Statistics has national higher education data for them.

8.6 THE PATTERN OF AUSTRALIAN DOMESTIC STUDENT PARTICIPATION IN STEM

This section examines trends in Australian domestic students' participation in STEM fields. Commencing enrolments and completions are examined at two course levels—bachelor's degree (the typical first degree in Australian higher education) and doctoral degree by research (PhDs, the typical research training qualification). These measures show the supply of students entering the higher education system in the STEM fields and the supply of graduates with STEM qualifications at the two primary course levels.

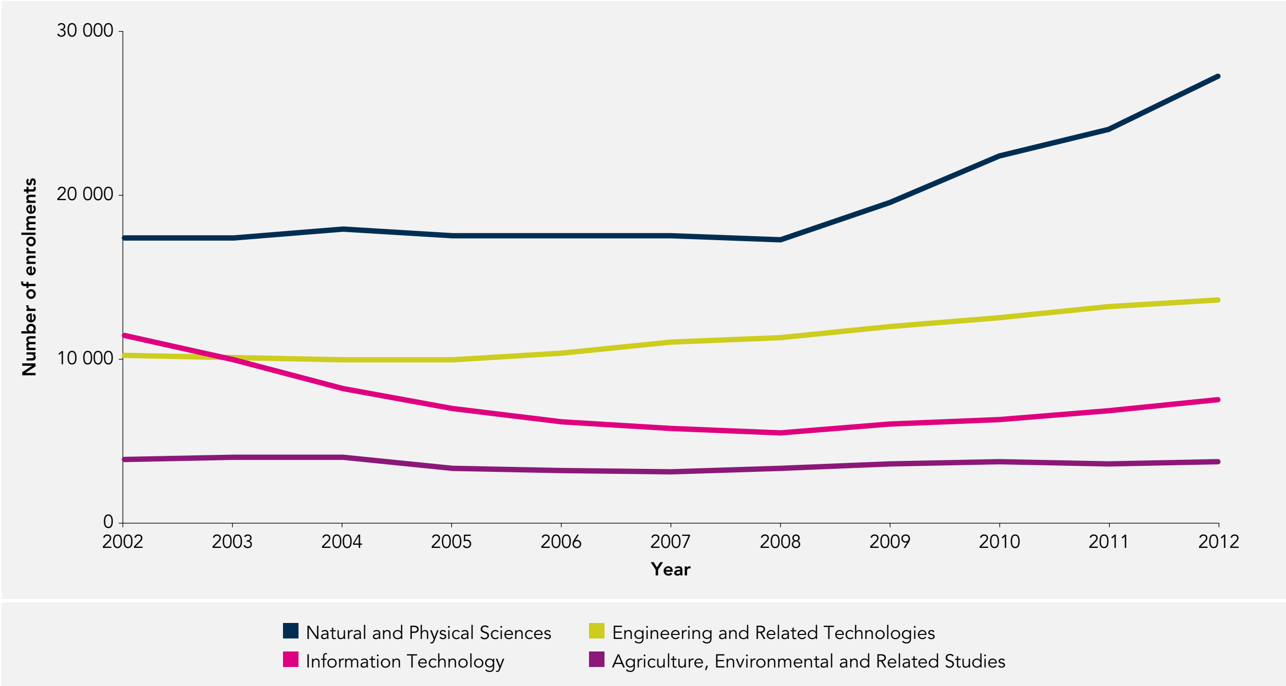
8.6.1 Undergraduates

Commencing enrolments in the STEM fields at the bachelor's level varied between 2002 and 2012 (see Figure 8-1). Commencing science enrolments (as shown by the education field natural and physical sciences) were steady from 2002 to 2008; they then grew by 57 per cent from 2008 to 2012. Some of this increase can be attributed to changes in degree structure at some universities—to the so-called Melbourne model, as mentioned—as opposed to changes in student preferences. The extent of the Melbourne model's effect on STEM enrolments is discussed shortly.

Engineering commencing enrolments were steady from 2002 to 2005, then grew by 37 per cent from 2006 to 2012. By contrast, agriculture and environment commencing enrolments changed little between 2002 and 2012. IT commencing enrolments dropped sharply in the early 2000s, declining by more than 50 per cent from 2002 to 2008; by 2012 they had recovered somewhat from their 2008 low, with growth of 37 per cent on 2008 levels. In total, almost 51 000 domestic students began a bachelor's degree in STEM in 2012, up from about 42 000 in 2002.

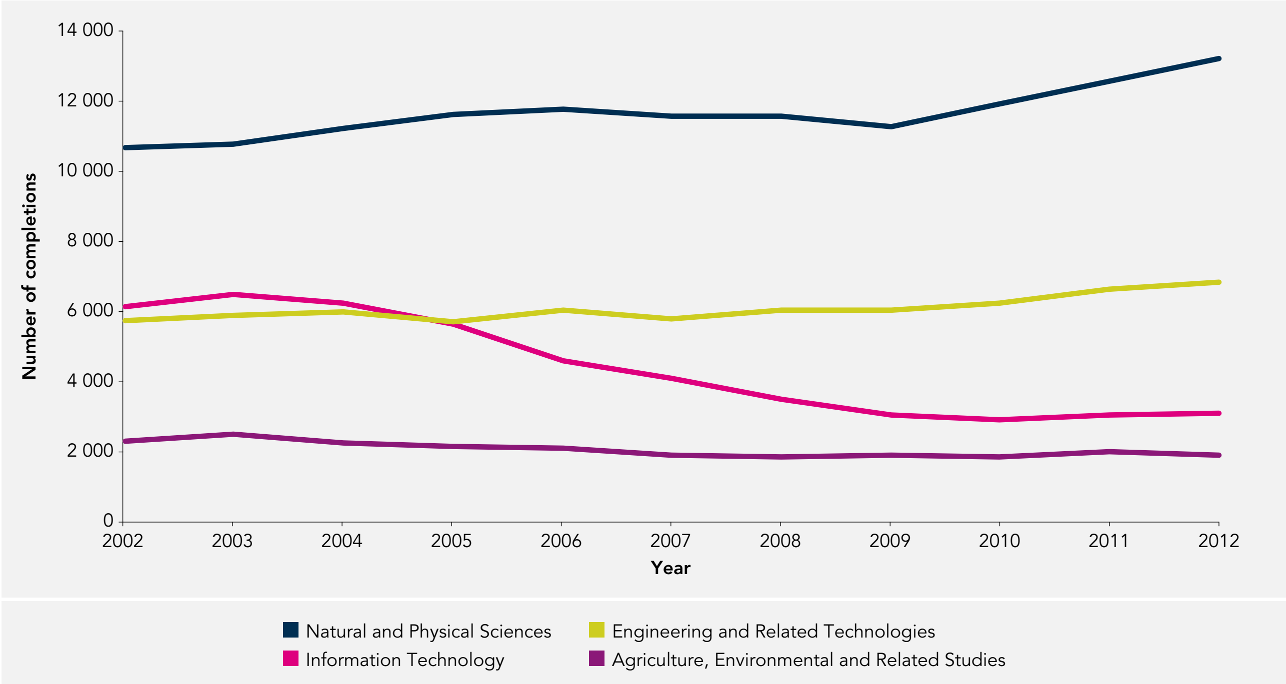
6 In 2012 10.7 per cent of domestic students commencing a STEM-field bachelor's degree were enrolled at the University of Melbourne and the University of Western Australia (Source: uCube, Department of Education).

Figure 8-1 Commencing enrolments in bachelor-level degrees for STEM fields: Australian domestic students, 2002 to 2012



Source: Department of Education, uCube.

Figure 8-2 Australian domestic student completions of bachelor-level degrees: STEM fields, 2002 to 2012



Source: Department of Education, uCube.

For those students not enrolled at Melbourne or the University of Western Australia commencing science enrolments (domestic students, bachelor's degrees) grew by 48 per cent from 2008 to 2012 (the figure was 57 per cent across all universities). On the other hand, at the restricted group of universities engineering grew by 52 per cent from 2005 to 2012 (only 37 per cent growth across all universities). The trends in IT and agriculture and environment are very similar whether Melbourne and UWA are excluded or not. Considering these trends in universities other than Melbourne and UWA, it seems the growth in student interest in science suggested by Figure 8-1 is overstated, while in engineering it is understated.

These data might also be affected by the reduction in the Higher Education Contribution Scheme fees for mathematics and science students implemented in 2009 (Australian Government 2008a). This policy reduced the 2009 HECS rate for commencing mathematics and science students from $7260 to $4077. The reduction was reversed for all students (commencing or continuing) from 2013 onwards (Australian Government 2008b). The purpose of the fee changes was to stimulate student interest in studying science and mathematics, and the changes were accompanied by rising enrolments in science courses. On the other hand, the Melbourne model directly affected the accounting of student participation in science and engineering. The challenge associated with these changes is that they coincided, complicating interpretation of the trends apparent in the data.

These confounders aside, the overall trend in recent years has been a rise in Australian domestic enrolments for natural and physical sciences and engineering. IT dropped sharply from 2002 to 2008 but has grown since then. Agriculture and environment enrolments in 2012 are largely unchanged from 2002.

8.6.2 STEM enrolments and broader enrolment trends

The trends just discussed raise the question of whether the changes are a result of changing student preferences or simply part of broader trends in university enrolments in Australia. The growth in commencing undergraduate enrolments in some of the STEM fields can be viewed in the context of expansion of the entire higher education system. Commencing bachelor's enrolments for Australian domestic students grew by 6 per cent from 2002 to 2008, from about 170 000 to about 180 000. They then grew by 29 per cent from 2008 to be 233 154 in 2012. Total growth from 2002 to 2012 was 39 per cent.

As discussed, trends in science, engineering and other STEM enrolments have been influenced by changes in degree structures at the universities of Melbourne and Western Australia. Taking these two universities out of the analysis, in 2008 science enrolments made up 8.8 per cent of commencing bachelor's degree enrolments; by 2012 this had grown to 10.0 per cent. In 2005 engineering's share of commencing enrolments was 5.5 per cent; by 2012 it was 6.1 per cent. Agriculture and environment enrolments made up 1.5 per cent of commencing enrolments in 2012, down from 2.3 per cent in 2002. IT enrolments dropped from 6.9 in 2002 to 3.4 per cent in 2012.

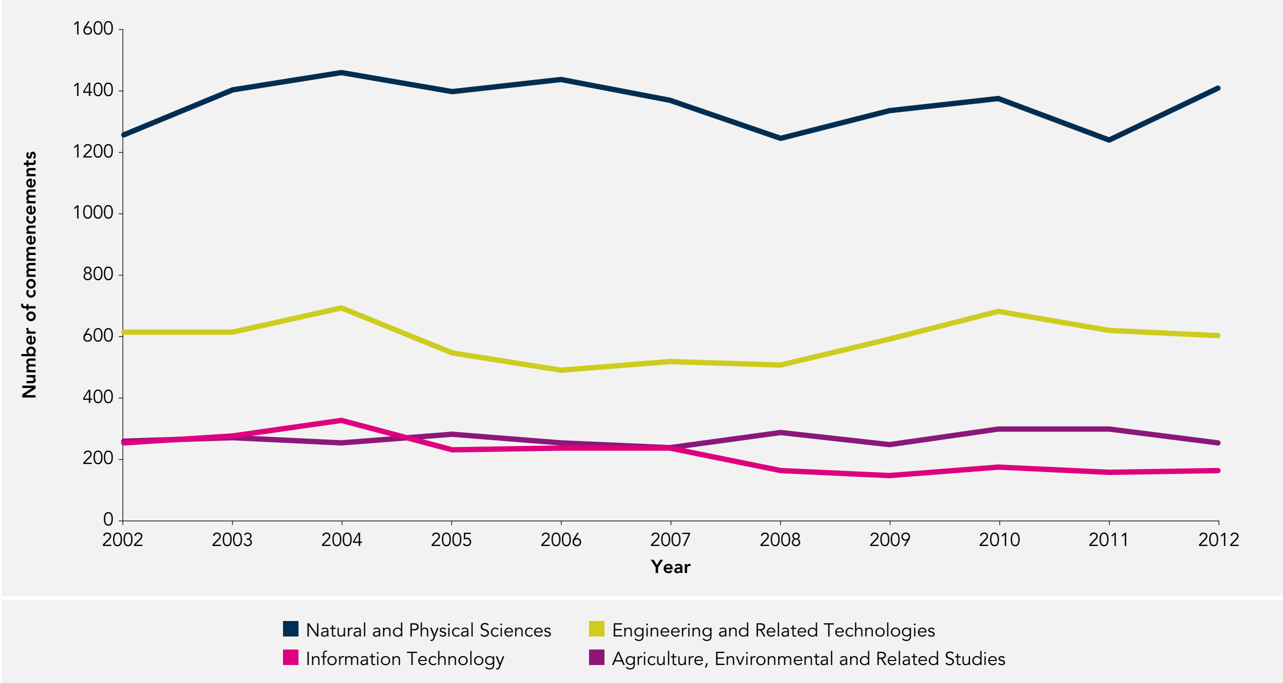
These results suggest that in recent years there has been increased interest in science and engineering bachelor's degrees by Australian students, beyond the growth that could be expected from expansion of the entire system and separate from enrolment changes brought about by the introduction of the Melbourne model. Growth in student interest in science coincided with the HECS discount for science students introduced in 2009. By contrast, agriculture and environment numbers have not kept up with the expanding system, there being a reduced share of enrolments in 2012. While IT declined significantly in the early 2000s, following a global change in fortunes for technology industries (Cornell University et al. 2014), from 2008 onwards it grew in line with overall enrolment numbers.

8.6.3 Students completing STEM degrees

Information about enrolments in particular degrees can cast light on the interests of students entering the higher education system. For many reasons, however, students might not continue in their enrolled degree, either changing to a different degree or discontinuing study. Completions are therefore an important measure of the output of the system: they directly measure the number of students that graduate in a specific field.

Bachelor's degree completions for the STEM fields showed trends similar to those for commencing enrolments, with science and engineering growing, IT falling sharply and agriculture and environment falling more slowly (see Figure 8-2). Natural and physical sciences bachelor's degree completions by domestic students grew by 24 per cent from 2002 to 2012; engineering completions grew by nearly 19 per cent during the same period. Completions in both IT and agriculture and environment fell by 50 and 18 per cent respectively.

Figure 8-3 Australian domestic students commencing doctorate by research degrees: fields, 2002 to 2012



Source: Department of Education, customised data set.

Introduction of the Melbourne model would influence graduation numbers from 2010 onwards (for students commencing in 2008 at Melbourne). Some of the graduating science students at Melbourne from 2010 onwards will have studied a science degree as a compulsory part of their pathway to engineering or medicine. As a result, it is possible that the observed growth in science completions overstates growth in the supply of science graduates entering either the workforce or further science education or research training.

8.6.4 Higher degrees by research: doctorates

Graduate education provides the capacity necessary for STEM workers to perform the highly skilled research and development roles needed by businesses that rely on STEM for innovation in knowledge-intensive industries. STEM research training in Australia has an emphasis on doctoral degrees rather than master's degrees. Master's degrees in STEM are not considered in this report, although they do represent one of the pathways for growing Australian STEM capability.

The total number of commencing enrolments in STEM fields at the research doctorate (PhD) course level was stable from 2002 to 2012, at 2374 in 2002 compared with 2393 in 2012. Commencing research doctorate enrolments for the STEM fields show that the trend in enrolments for the STEM fields differs from that for bachelor's degrees (see Figure 8-3). Natural and physical sciences had the greatest number of commencing doctorate enrolments from 2002 to 2012; this was followed by engineering.

Domestic students' enrolments in STEM doctorates can be viewed in the context of research training in all fields of education. As Table 8-2 shows, commencing doctoral enrolments across all fields of education increased from 6181 in 2002 to 6856 in 2012.

Domestic students' commencing research doctorate enrolments in 2012 in the combined STEM fields accounted for 35 per cent of all doctorate enrolments. Natural and physical science contributed 20 per cent of commencing doctorates, engineering 9 per cent, and agriculture and environment 4 per cent.

Commencing doctorate enrolments in IT declined by approximately 35 per cent from 2002 to 2012, making up 2 per cent of commencing doctorates in 2012.

Table 8-2 Australian domestic students commencing doctorate by research degrees: all fields, 2002 to 2012

Year	Total commencing doctorates
2002	6181
2003	6506
2004	6582
2005	6322
2006	6422
2007	6448
2008	6104
2009	6304
2010	6737
2011	6874
2012	6856

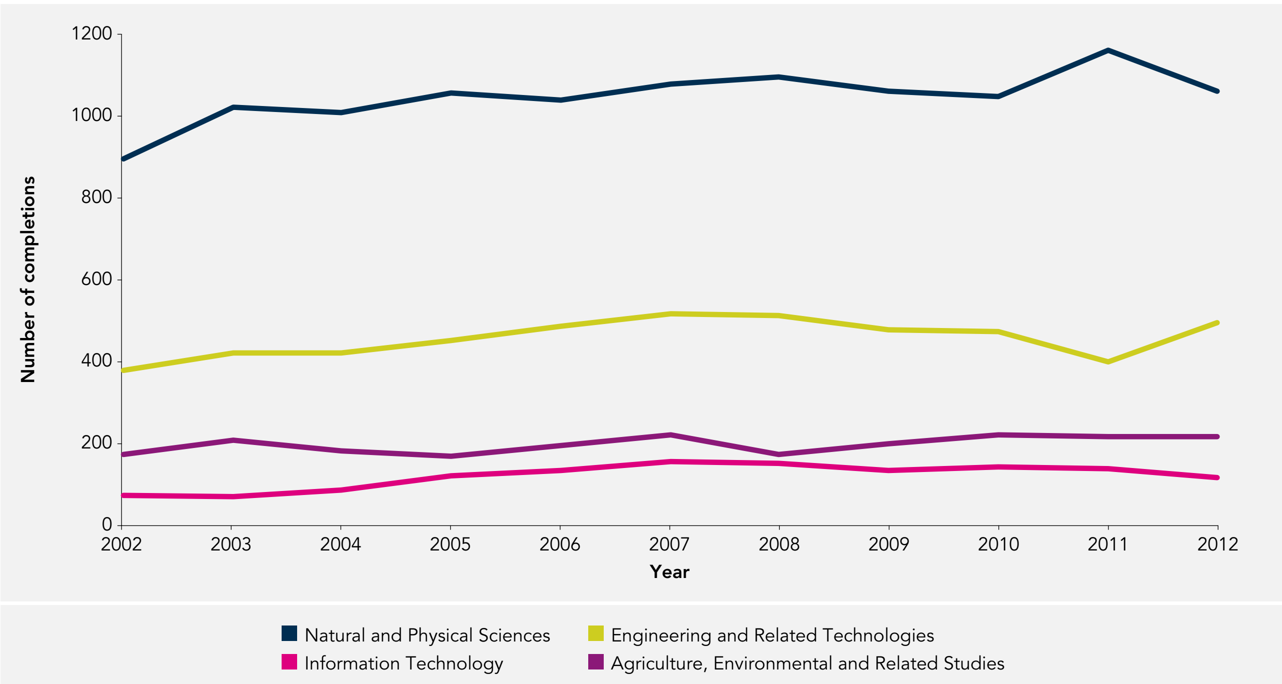
Source: Department of Education, customised data set.

Research doctorate completions across all the STEM fields increased from 1524 in 2002 to 1888 in 2012 (see Figure 8-4). This represents 41 per cent of all doctorate completions—down from 45 per cent in 2007. Doctorate completions in each individual STEM field grew in absolute terms between 2002 and 2012, but only IT and engineering completion growth rates were higher than the rate of growth for total completions, which was 26 per cent from 2002 to 2012.

Science doctorate completions, which made up 25 per cent of all doctorates awarded in 2002, declined to 23 per cent in 2012.

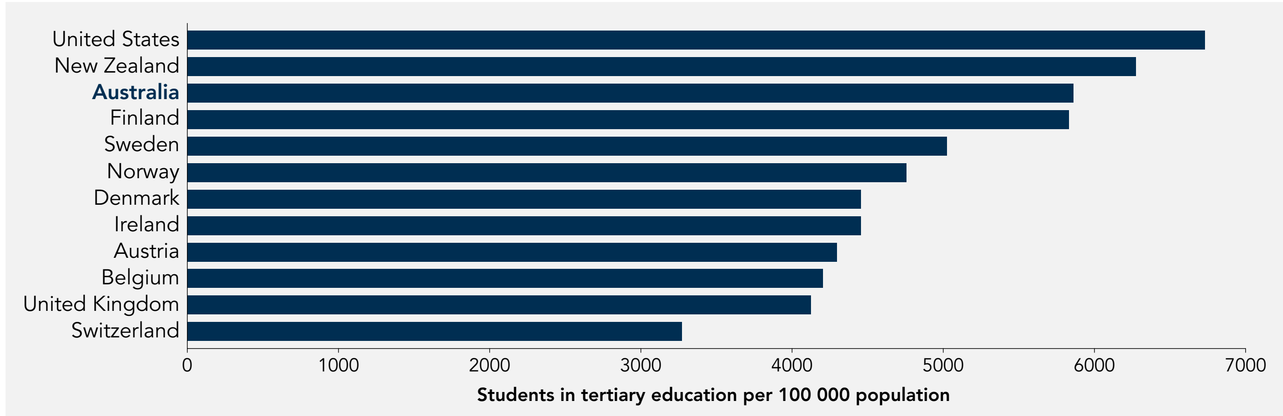
Overall, this shows a relatively constant number of STEM doctoral candidates in the Australian education system, with an emphasis on the natural and physical sciences over other STEM fields. Although the trends in enrolment and completion provide valuable insights into the Australian education system, it is important to compare these data with international benchmarks in order to understand how Australia sits in the global context.

Figure 8-4 Australian domestic student completions of doctorates by research: STEM fields, 2002 to 2012



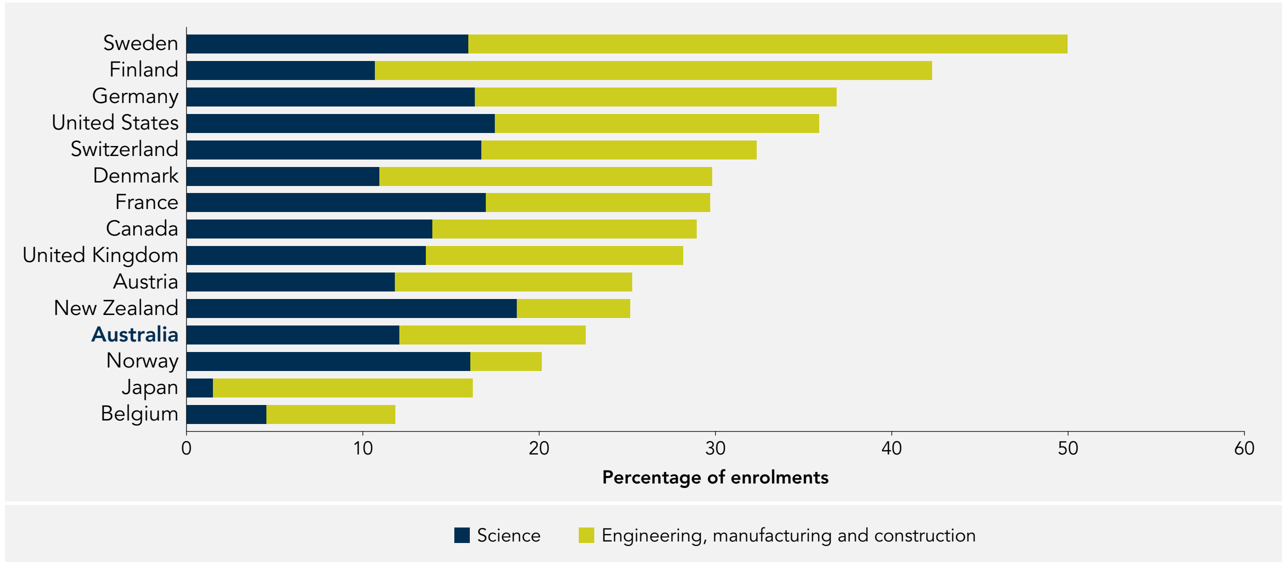
Source: Department of Education, customised data set.

Figure 8-5 Students enrolled in first degree in tertiary education per 100 000 population, selected countries, 2010



Source: UNESCO, Tertiary Country Comparison, customised data set.

Figure 8-6 Distribution of student enrolments in first degrees in tertiary education: science and engineering, manufacturing and construction, selected countries, 2009



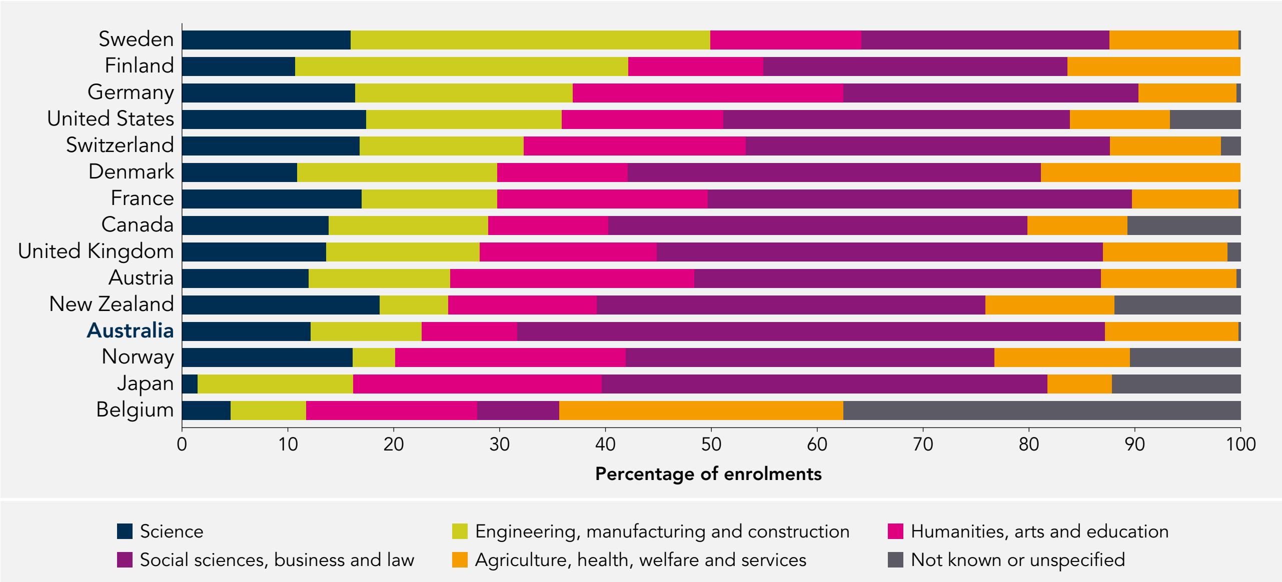
Source: OECD (2011).

8.7 AUSTRALIA'S PRODUCTION OF STEM DEGREE HOLDERS IN THE INTERNATIONAL CONTEXT

The size of a nation's higher education system in part reflects the size of its population. If enrolment numbers are adjusted for population size, the relative emphasis in a country on producing people with tertiary qualifications in particular fields becomes apparent.

In all education fields, the relative number of students enrolled in first degrees in tertiary education in Australia was 5884 per 100 000 population in 2010—lower than in the United States (6748 per 100 000) and New Zealand (6291 per 100 000) but higher than in several European nations (see Figure 8-5).

Figure 8-7 Distribution of student enrolments in first degrees in tertiary education, by field of education, selected countries, 2009



Note: Information for Canada is for 2008.

Source: OECD (2011).

8.7.1 How does the field profile of Australian higher education compare internationally?

UNESCO classifies first, or bachelor's, degrees according to their course content into fields of education (see Table 8-1). In 2010 Australia had a higher proportion (12.1 per cent) of all bachelor's degree enrolments in the field of natural sciences, mathematics and statistics (science) than Japan, Belgium, Finland, Denmark and Austria (see Figure 8-6). Several other countries had a higher proportion of first degrees in science—Germany (16.4 per cent), France (17 per cent), the United States (17.5 per cent) and New Zealand (18.7 per cent). Countries also varied in the proportion of first degree enrolments in the field of engineering, manufacturing and construction (engineering). Of the 14 countries chosen for comparison, only Norway, Belgium and New Zealand had lower proportions of enrolments in engineering than Australia. The remaining 11 had higher rates of engineering enrolments.

When considering the total cohort of students for science and engineering, manufacturing and construction, 22.7 per cent of Australian student enrolments are in these fields—lower than all countries assessed apart from Norway, Japan and Belgium.

When this analysis is extended to all the fields of education, it is evident that social sciences, business and law have the greatest share of first degree enrolments outside the STEM fields for nearly all the countries compared (see Figure 8-7).

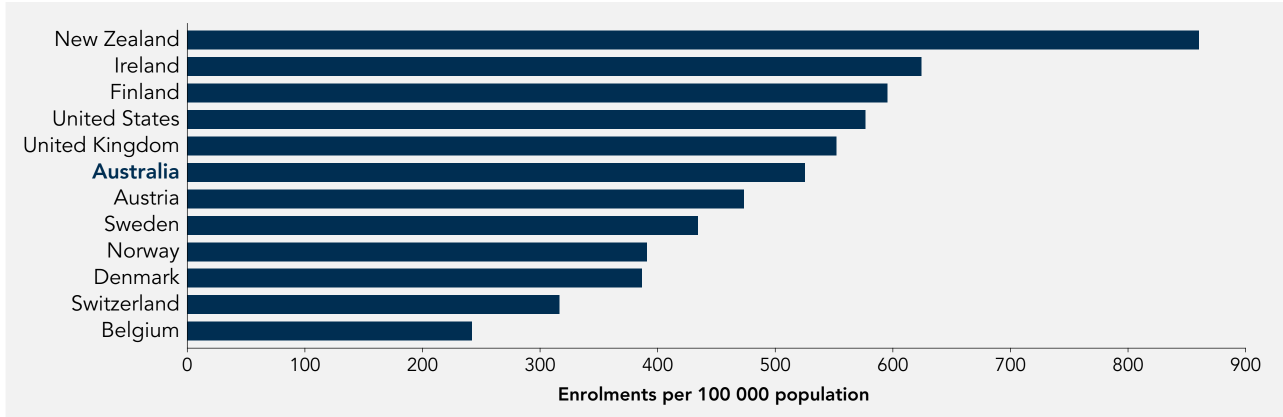
8.7.2 How does Australia's rate of STEM enrolments compare internationally?

In 2010 Australia had 525 bachelor's enrolments in science per 100 000 population (see Figure 8-8). This is below the rate of science enrolments in the United Kingdom (552 per 100 000), the United States (577), Finland (596), Ireland (625) and New Zealand (861). Australia is in the middle of the countries analysed, which represents a moderate emphasis in Australia on developing STEM graduates.

8.7.3 How does Australia's output of science and engineering doctorates compare internationally?

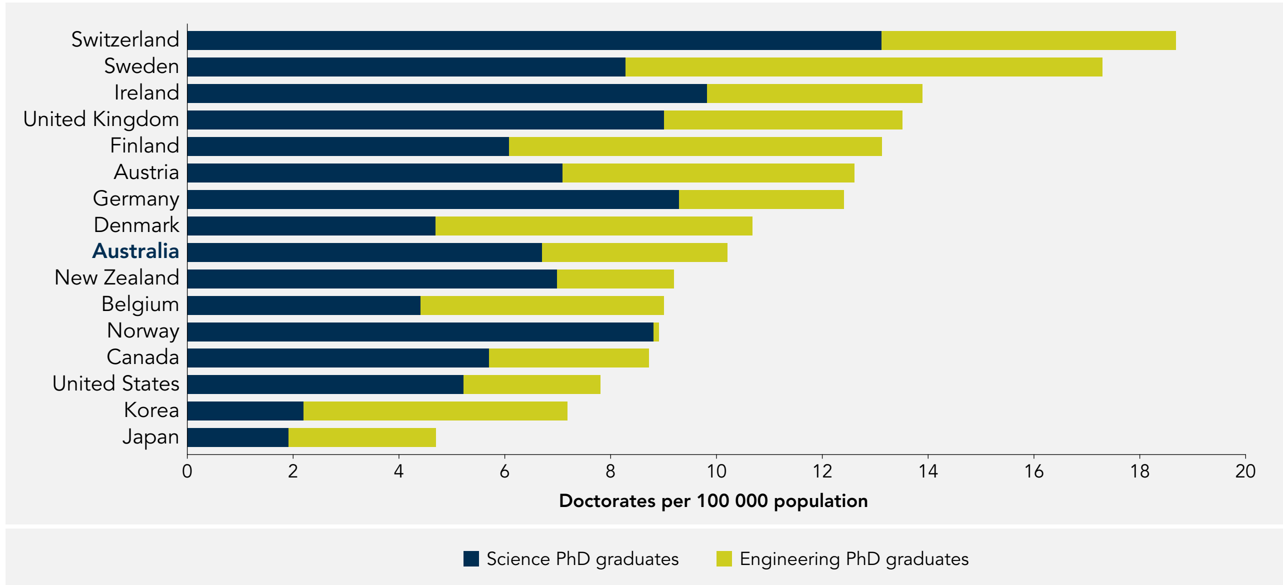
More than 200 000 science and engineering doctorates were awarded worldwide in 2010. A comparison of selected countries reveals that the number of science and engineering doctorates awarded per 100 000 population ranged from 5 to 18 (see Figure 8-9). In contrast with Switzerland's 18 per 100 000 and Japan's 5 per 100 000,

Figure 8-8 Students enrolled in first degree in tertiary science per 100 000 population, selected countries, 2010



Source: UNESCO, Tertiary Country Comparison, customised data set.

Figure 8-9 Science and engineering doctoral graduates per 100 000 population, selected countries, 2010



Source: OECD, Main Science and Technology Indicators, January 2014.

Australia awarded 10 science and engineering doctorates per 100 000 population in 2010.

8.8 FUNDING AND SUPPORT FOR HIGHER DEGREE BY RESEARCH STUDENTS

Research is one of the main activities in Australian universities. Universities compete for government funding aimed at covering the direct and indirect costs of research, including research training. The indirect cost of research is supported by Commonwealth research block grants. Grant amounts under the research block grant schemes are determined entirely by research performance. The performance measures are research income, research publications, higher degree by research student completions, and higher degree by research student load.

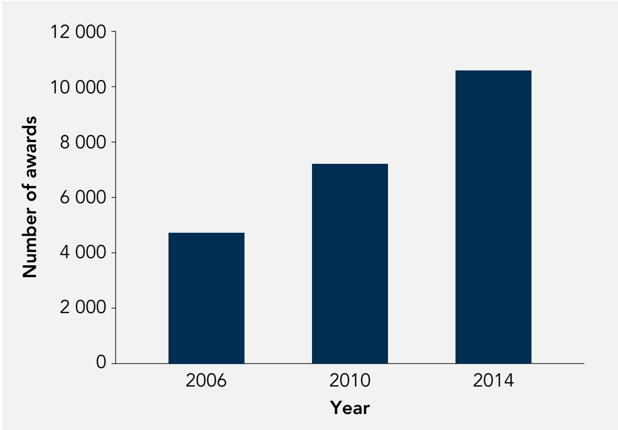
Each calendar year the Research Training Scheme provides block grants to eligible Australian higher education providers to support research training for students doing doctorate by research and master's by research degrees.

The growth in funding of this scheme in recent years has been based on inflation, so funding has not changed in real terms from year to year.

Another mechanism for funding research training is the Australian Postgraduate Award program. Funding for APA scholarships is provided through the performance-based research block grant scheme. Universities then award the scholarships to students with exceptional potential who are studying for a doctorate or master's by research. Since 2006 the government has increased funding in this mechanism and the estimated number of domestic higher degree by research students supported by an APA has doubled (see Figure 8-10). This includes both commencing and continuing students.

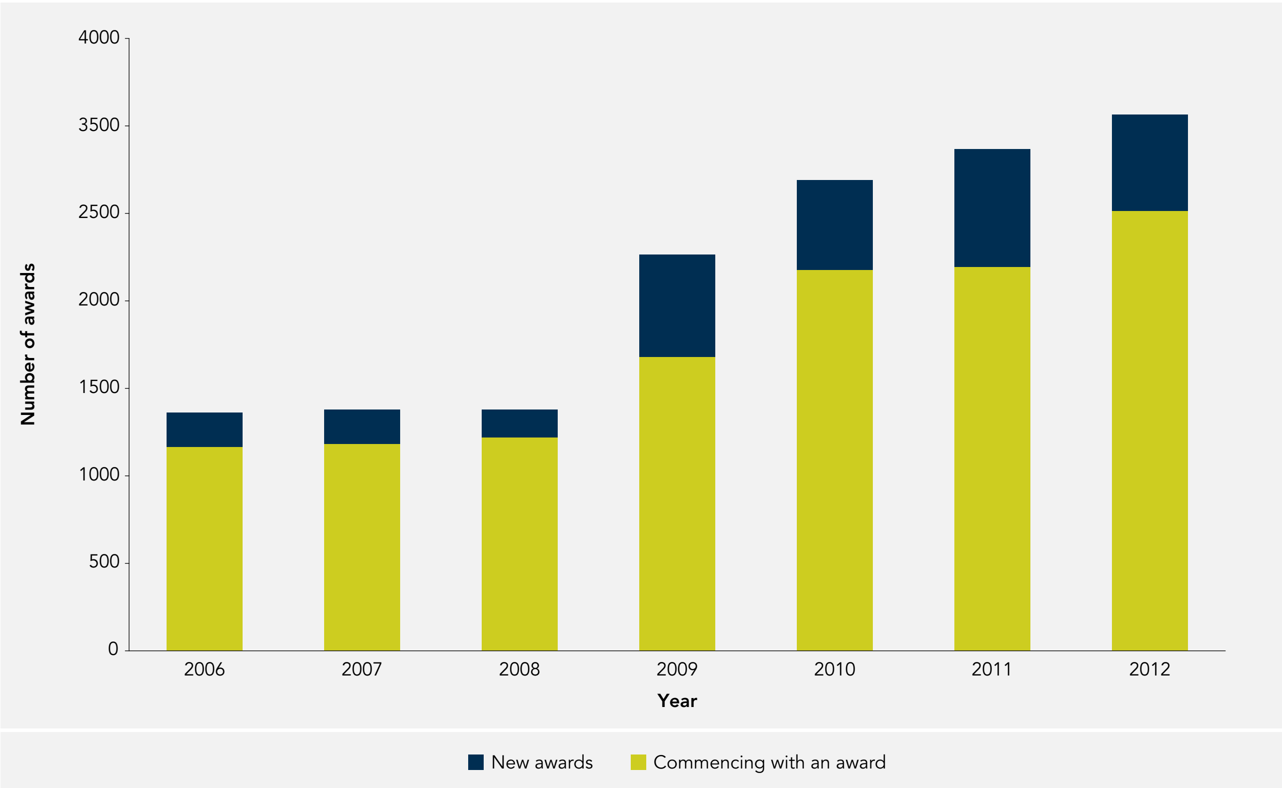
In recent years there has been growth both in the number of new Australian Postgraduate Awards allocated to universities and in the number of such awards actually awarded and taken up by commencing higher degree by

Figure 8-10 Total Australian Postgraduate Award students: all fields, 2006 to 2014



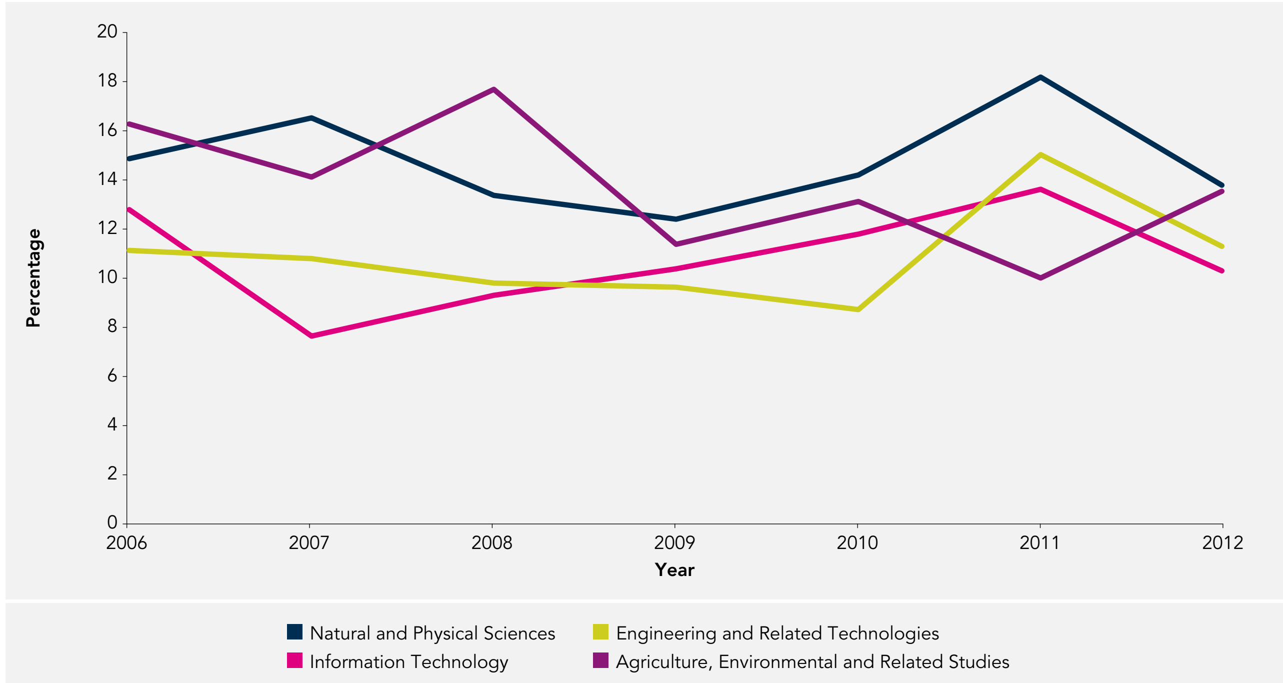
Note: Includes both commencing and continuing students.
Source: Department of Education.

Figure 8-11 New Australian Postgraduate Awards for higher degree by research and commencing award recipients, 2006 to 2012



Source: Department of Education, customised data set.

Figure 8-12 Proportion of STEM PhD completions supported by an Australian Postgraduate Award, 2006 to 2012



Source: Department of Education, customised data set.

research students (see Figure 8-11). Each year from 2006 to 2012 there has been a surplus of APA grants available but not awarded to commencing students. In 2006, 85 per cent of available APAs were awarded, leaving 236; in 2012, 82 per cent were awarded, leaving 627. In total, from 2006 to 2012, 17 149 APAs were allocated to universities, but only 13 850 students commenced with an APA.

Despite the growth in the number of new APAs, only a small proportion of PhD completions in Australia have been supported by such an award. Most PhD students are supported through other means—such as Research Training Scheme funding. The proportion of STEM-field PhDs awarded each year that were supported by an APA fluctuated from 2006 to 2012 (see Figure 8-12). In natural and physical sciences, support levels ranged from 11.4 per cent in 2009 to 18.2 per cent in 2011. Engineering and IT PhDs had lower levels of APA support, ranging from 7.6 to 15.0 per cent. Agriculture saw a decline in APA support, from 16.3 to 13.5 per cent between 2006 and 2012.

8.9 CONCLUDING REMARKS

In comparison with selected developed nations, Australia has a relatively high rate of per capita enrolments in tertiary education, but there is less emphasis on STEM. We sit in the middle of the comparator countries as measured by our relative rate of science undergraduate enrolments and the number of science and engineering doctorate holders per capita.

STEM research skills are recognised as important in knowledge-intensive industries. The availability of funding and support for talented Australian STEM doctoral students (our primary source of research-trained workers) is crucial if Australia is to expand its knowledge economy.

CHAPTER 9

9. SCHOOLS

This chapter analyses the performance of the Australian school system, with a focus on student performance in international testing, teaching in science and mathematics, and participation rates in senior school mathematics and science.

9.1 MAIN FINDINGS

- In the OECD Programme for International Student Assessment, 15-year-old Australian students (primarily year 10) score higher than the OECD average for both scientific and mathematical literacy.
- The PISA results show that Australian students' performance in mathematical literacy declined between 2003 and 2012, but there was no significant change in scientific literacy between 2006 and 2012.
- Out of 17 selected comparator countries, seven significantly outperformed Australia in mathematical literacy in 2012; this compares with three in 2003.
- Australia's relative and absolute performance in science and mathematics (year 4 and year 8), as measured by the Trends in International Mathematics and Science Study, has changed little over a number of assessment cycles.
- The TIMSS data show that about a third of year 8 mathematics teachers had neither a major in mathematics nor training in mathematics teaching methodology as part of their teacher preparation.
- Forty per cent of high school mathematics teachers have not studied mathematics to at least second-year level at university. Of the same group, about 40 per cent have not studied teaching methodology in mathematics.
- The required average teaching time for mathematics in Australian primary schools is the same as the OECD average of 17 per cent of total weekly teaching time; the required average time for teaching science in Australian primary schools is 5.7 per cent of total weekly teaching time, below the OECD average of 7.4 per cent.
- Participation rates in year 12 science and mathematics subjects show that in the past 20 years participation in science subjects and advanced or intermediate-level mathematics has declined, while participation in entry-level mathematics has increased.

9.2 BACKGROUND

Economic growth cannot be sustained in the absence of a community of inquiring and capable people, a steady pipeline of specialist STEM skills in the workforce, and general science and mathematical literacy in the community.

The STEM pipeline begins in schools, which play a crucial role in stimulating and nurturing student interest in STEM disciplines. These fields are perceived as 'hard' by some students (ATSE 2013; Goodrum et al. 2011), and early engagement and inspirational teaching are essential to help students see the benefits of learning—and excelling at—STEM. Australia's STEM teachers at all levels, from primary to tertiary, need to be equipped to deliver inspirational course content and develop all students to their full potential.

Australia also needs school curricula that give priority to inquiry-based learning and the development of problem-solving and higher order thinking skills that will help students learn about STEM and the way STEM is practised. In turn, students of STEM disciplines must be able to see clear pathways from the classroom to a rewarding career.

9.3 DATA SOURCES AND TERMINOLOGY

The OECD Programme for International Student Assessment is an international survey designed to assess 15-year-old students' competencies in reading, mathematics and science.

In Australia PISA data are collected by the Australian Council for Educational Research. Students take a two-hour paper-based test containing open-ended and multiple choice items. They and their principals answer 30-minute questionnaires. The student questionnaire seeks information about students' backgrounds, perceptions and learning experiences; the questionnaire for principals seeks information about school learning environments and the broader school system.

Australian students also participate in the Trends in International Mathematics and Science Study (Thomson et al. 2012b). TIMSS is directed by the International Association for the Evaluation of Educational Achievement, an independent cooperative of national research institutions and government agencies from around the world. In Australia TIMSS is carried out by the Australian Council for Educational Research. It has assessed mathematics and science in 1995, 2003, 2007 and 2011 for students in year 4 (primary school) and in 1995, 1999, 2003, 2007 and 2011 for students in year 8 (secondary school). In addition to the student tests, teachers, principals and students complete questionnaires to provide information about their backgrounds, experiences and the learning environment. TIMSS data on year 8 teachers' qualifications are presented here.

In addition to TIMSS, ACER collects information about teacher qualifications through its Staff in Australia's Schools survey, conducted every three years (McKenzie et al. 2011). The latest published data are from the 2010 survey.

The regulated time each country spent in teaching science and mathematics to school students was compiled by the OECD Directorate for Education and Skills and is published in *Education at a Glance 2013* (OECD 2013). Australia was not included in this report for these data, so the regulated time spent teaching science and mathematics in Australian schools is derived from the Australian Curriculum Assessment and Reporting Authority's recommended indicative teaching hours, which were endorsed by Australian state and territory education ministers (ACARA 2013). Recent estimates are not available to show whether or how widely this target is met. The participation rates for Australian year 12 students in science and mathematics subjects are from 'The continuing decline of science and mathematics enrolments in Australian high schools' (Kennedy et al. 2014).

9.4 COUNTRIES ANALYSED

As with previous chapters, two groups of benchmarking nations were identified for analysis—countries at stages of development similar to that of Australia and with similar governance systems (the United States, Canada and selected European nations) and selected countries in the Asia–Pacific region.

In this chapter Australia is compared with Austria, Belgium, Canada, Denmark, Finland, France, Germany, Indonesia, Ireland, Japan, South Korea, New Zealand, Norway, Singapore, Sweden, Switzerland, Thailand, the United Kingdom and the United States where data were available. Where comparisons of test results are made over time or for different student age groups, comparator countries that had participated at both time points or for both age groups were chosen.

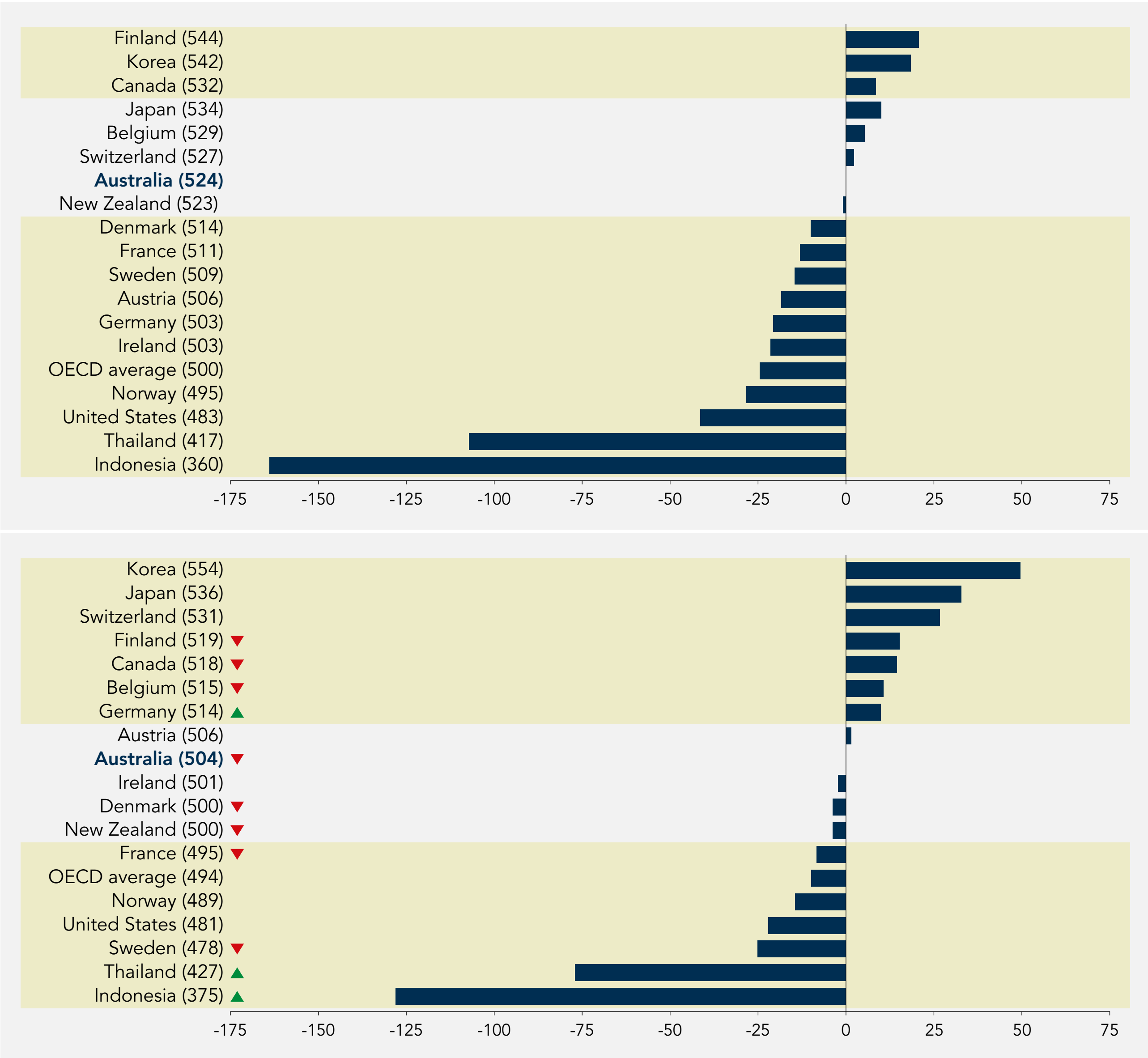
9.5 PERFORMANCE OF AUSTRALIAN SECONDARY SCHOOL STUDENTS IN MATHEMATICS AND SCIENCE

9.5.1 PISA mathematical literacy, 2003 to 2012

The OECD Programme for International Student Assessment conducts surveys every three years to assess the competencies of 15-year-olds in reading, mathematics and science. Each cycle has a focus on one of these domains. Once a domain has been the focus of a PISA cycle, results for that year can be compared with results for later cycles. Comparisons depend on common items being used in the successive cycles. Mathematics was the focus of the 2003 PISA, so trends in mathematical literacy can be observed from 2003 onwards.

Figure 9-1 shows mean scores for 2003 and 2012 in mathematical literacy for 17 comparator countries. To allow an assessment of Australia's relative performance over time, only countries that participated in both years are included. The OECD average is the average of all participating OECD countries' mean scores. Each country's mean score is shown in parentheses, and the bars show the difference

Figure 9-1 PISA mathematical literacy mean country scores relative to Australia, 2003 and 2012



Notes: Countries are ranked by their mean score (in parentheses). The bars indicate the difference in mean score relative to Australia. Shaded areas show countries whose performance was significantly different to Australia's (using a 95% confidence interval of the mean). Countries that demonstrated a significant change in performance from 2003 to 2012 are labelled with an arrow showing the direction of the change. Japan is positioned below Canada in the 2003 listing despite having a higher mean score. This is because the larger standard error in Japan's score renders it not significantly different statistically from Australia's, while the score for Canada was.

Source: OECD (2013).

in their score relative to Australia. Where a country's 2012 score showed a significant change from 2003, an arrow shows the direction of change.

Australia's mean score has changed in both absolute and relative terms. Its score of 524 in 2003 declined to 504 in 2012. This decline is statistically significant (using a 95 per cent confidence interval of the mean). In 2003 three of the 17 comparator countries significantly outperformed Australia; in 2012 seven did.

Australia was not alone in showing an absolute performance decline from 2003 to 2012: Finland, Canada, Belgium, Denmark, New Zealand, France and Sweden also experienced declines. Countries that improved their ranking relative to Australia did so by maintaining their scores from 2003 to 2012 (Japan, Switzerland, Ireland and Austria) or improving their performance (Germany, the only developed nation to do so in this group).

PISA provides details on student performance in addition to mean country scores. The results profile students according to proficiency levels (Level 1 to Level 6). Internationally, Level 2 is considered to be a baseline at which students start to demonstrate skills that will allow them to actively participate in life situations (Thomson et al. 2012a). The decline in mathematical literacy indicated by PISA has been across the proficiency scale. The proportion of low performers (where students fail to reach Level 2) increased from 14 per cent in 2003 to 20 per cent in 2012. The proportion of Australian students who are top performers (reaching Level 5 or above) declined from 20 to 15 per cent during that period.

The 2003 to 2012 decline in PISA mathematical literacy scores differed by gender and between Indigenous and non-Indigenous students. The mean mathematical performance of Australian female students declined by 24 points to 498, while that for males declined by 17 points to 510.

9.5.2 PISA scientific literacy, 2006 to 2012

Science was first the focus of PISA in 2006, so scientific literacy comparisons can be made from that time on.

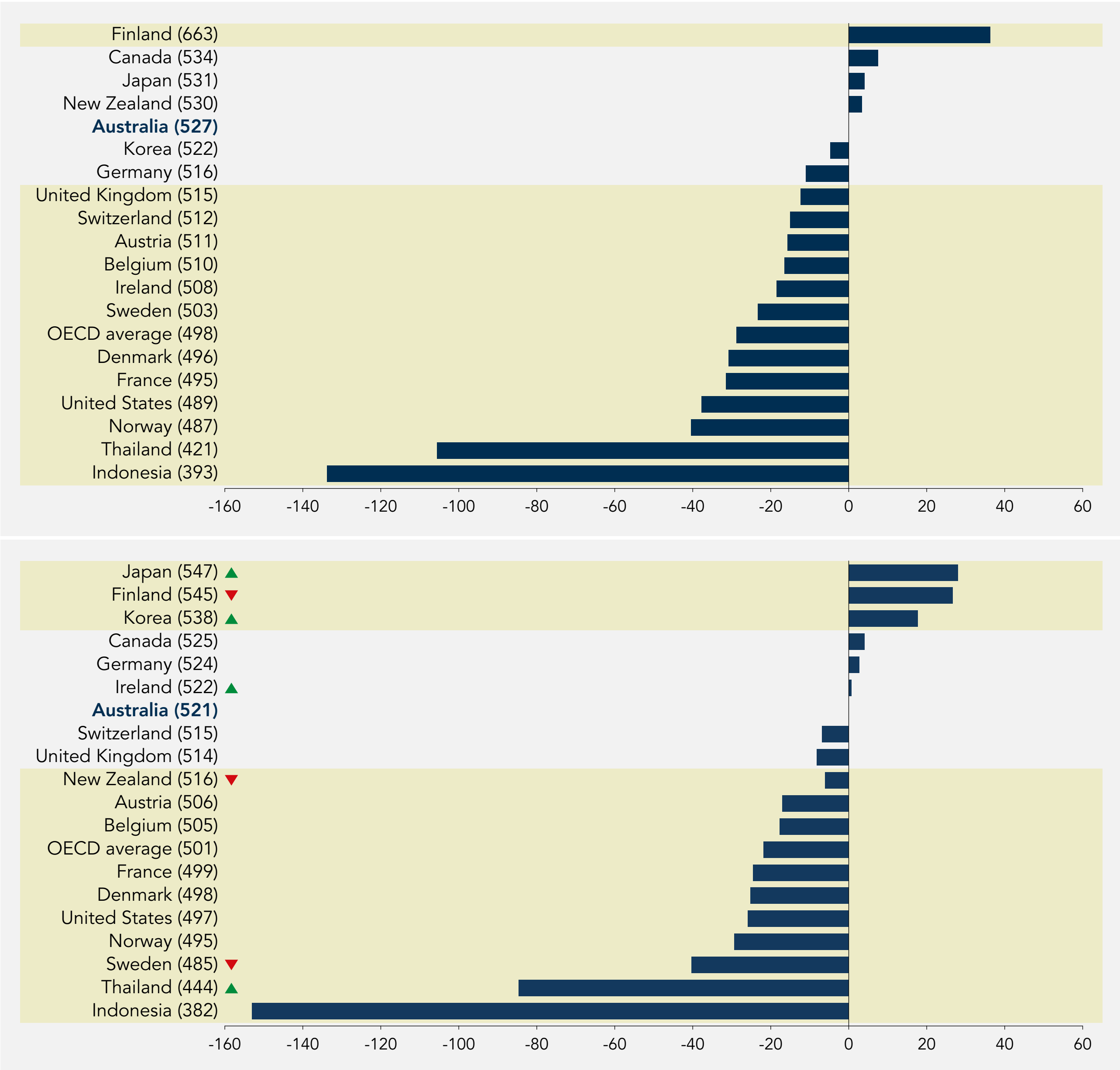
Figure 9-2 shows mean scores for 2006 and 2012 in scientific literacy for 17 comparator countries. To allow an assessment of Australia's relative performance over time, only comparator countries that participated in both years are included. The OECD average is the average of all participating OECD countries' mean scores. Each country's mean score is shown in parentheses, and the bars show the difference in their score relative to Australia. Where a country's 2012 score showed a significant change from 2006, an arrow shows the direction of change.

Australia's mean score for scientific literacy has changed little in absolute and relative terms. The score of 527 in 2006 declined to 521 in 2012 (see Figure 9-2). Out of 18 comparator countries, in 2006 only Finland significantly outperformed Australia. Japan and Korea increased their scores significantly between 2006 and 2012, joining Finland in the list of comparator countries outperforming Australia. Ireland, Switzerland and the United Kingdom increased their positions relative to Australia, from significantly lower in 2006 to about the same as Australia in 2012.

Australia's trend in mean science scores over time is similar to that for many comparator countries—that is, no significant change from 2006 to 2012. The exceptions are Finland, New Zealand and Sweden, which suffered significant declines in their scientific literacy scores from 2006 to 2012.

There was no significant change in the proportions of top and low performers from 2006 to 2012.

Figure 9-2 PISA scientific literacy mean country scores relative to Australia, 2006 and 2012



Notes: Countries are ranked by their mean score (in parentheses). The bars indicate the difference in mean score relative to Australia. Shaded areas show countries whose performance was significantly different to Australia's (using a 95% confidence interval of the mean). Countries that demonstrated a significant change in performance from 2006 to 2012 are labelled with an arrow showing the direction of the change. New Zealand is positioned below Switzerland and the United Kingdom in the 2012 listing despite having a higher mean score. This is because the standard error in New Zealand's 2012 score rendered it significantly lower statistically than Australia's, while the smaller standard errors in the scores for Switzerland and the United Kingdom did not.

Source: OECD (2013).

Table 9-1 Mean mathematics achievement in TIMSS 2011: year 4 and year 8, selected countries

Year 4		Year 8	
Singapore	605	Korea	613
Korea	605	Singapore	611
Japan	585	Japan	570
Finland	545	Finland	514
England	542	United States	509
United States	541	England	507
Australia	516	Australia	505
Sweden	504	New Zealand	488
Norway	495	Sweden	484
New Zealand	486	Norway	475
Thailand	458	Thailand	427

Notes: The TIMSS achievement scale is normalised, setting 500 points as the mean of overall achievement, with a standard deviation of 100 points. In TIMSS 2011 there were 52 participating countries in the year 4 assessment and 45 in the year 8 assessment. Yellow shading indicates countries with a mean mathematics achievement not significantly different from that of Australia.

Source: TIMSS 2011 international results in mathematics.

9.5.3 TIMSS performance: science and mathematics

Not every country has participated in every cycle of TIMSS: some have joined in recent years; others have participated on and off. This makes inter-country comparisons going back through the cycles difficult. As a result, this section focuses on 2011 results.

Table 9-1 presents the mean mathematics achievement results for comparator countries that participated in TIMSS in 2011, for years 4 and 8. Countries are ranked by their mean score. Countries that outperformed Australia (using a 95 per cent confidence interval of the mean) are listed above Australia; those that Australia outperformed are listed below.

Australia's performance relative to this group of countries is similar for year 4 and year 8 students. The main difference is that year 4 students in Finland, England and the United States performed significantly better than Australian students on average, while year 8 students from those countries performed similarly to Australian students.

In addition to those shown in Table 9-1, a number of other comparator countries outperformed Australia in TIMSS based on year 4 mean mathematical achievement scores. They are not shown in the table because they did not participate in the year 8 mathematical TIMSS. These countries and their 2011 year 4 mathematical achievement scores are Northern Ireland (562), Belgium (549), Denmark (537), Germany (528) and Ireland (527).

Looking back at previous rounds of TIMSS in which the comparator countries participated, Australia's relative position has changed little. For the most part, countries that outperform us now have done so in the past (Thomson et al. 2012b, 2012c). The same goes for countries that we outperform. Two notable exceptions are England and the United States. In 1995 Australia significantly outperformed England in both year 4 and year 8 mathematical achievement; by 2011, however, England had a higher score for both groups (significantly higher for year 4 students, higher but not significantly so for year 8). The United States also improved its position relative to Australia (year 8 students) between 1995 and 2011.

Table 9-2 presents the mean science achievement results for comparator countries that participated in the 2011 TIMSS in both years 4 and 8. Countries are ranked by their mean score. Countries that outperformed Australia (using a 95 per cent confidence interval of the mean) are listed above Australia; those that Australia outperformed are listed below.

Australia's performance relative to this group of countries is similar for year 4 and year 8 students. The main difference is that more countries had a significantly higher mean science score than Australia based on year 4 results compared with year 8.

In addition to those shown in Table 9-2, a number of other comparator countries outperformed Australia on year 4

Table 9-2 Mean science achievement in TIMSS 2011: year 4 and year 8, selected countries

Year 4		Year 8	
Korea	587	Singapore	590
Singapore	583	Korea	560
Finland	570	Japan	558
Japan	559	Finland	552
United States	544	England	533
Sweden	533	United States	525
England	529	Australia	519
Australia	516	New Zealand	512
New Zealand	497	Sweden	509
Norway	494	Norway	494
Thailand	472	Thailand	451

Notes: The TIMSS achievement scale is normalised, setting 500 points as the mean of overall achievement, with a standard deviation of 100 points. In TIMSS 2011 there were 52 participating countries in the year 4 assessment and 45 countries in the year 8 assessment. Yellow shading indicates countries with a mean science achievement not significantly different from that of Australia.

Source: TIMSS 2011 international results in science.

science TIMSS indicators. As with mathematics, they did not participate in the year 8 science TIMSS. These countries and their 2011 year 4 science achievement scores are Austria (532), Germany (528) and Denmark (528), all of which increased their ranking relative to Australia between the 2007 TIMSS and the 2011 TIMSS.

9.6 QUALIFICATIONS AND TRAINING OF MATHEMATICS AND SCIENCE TEACHERS

As well as student testing, TIMSS requires school principals and the students' mathematics and science teachers to complete detailed questionnaires. The data used in this section were reported by teachers.

At the year 8 level, 67 per cent of Australian students were taught mathematics by teachers with a major in mathematics or mathematics education, or both (see Figure 9-3). This is lower than the level for all but one comparator country for which there are TIMSS data on teacher preparation.

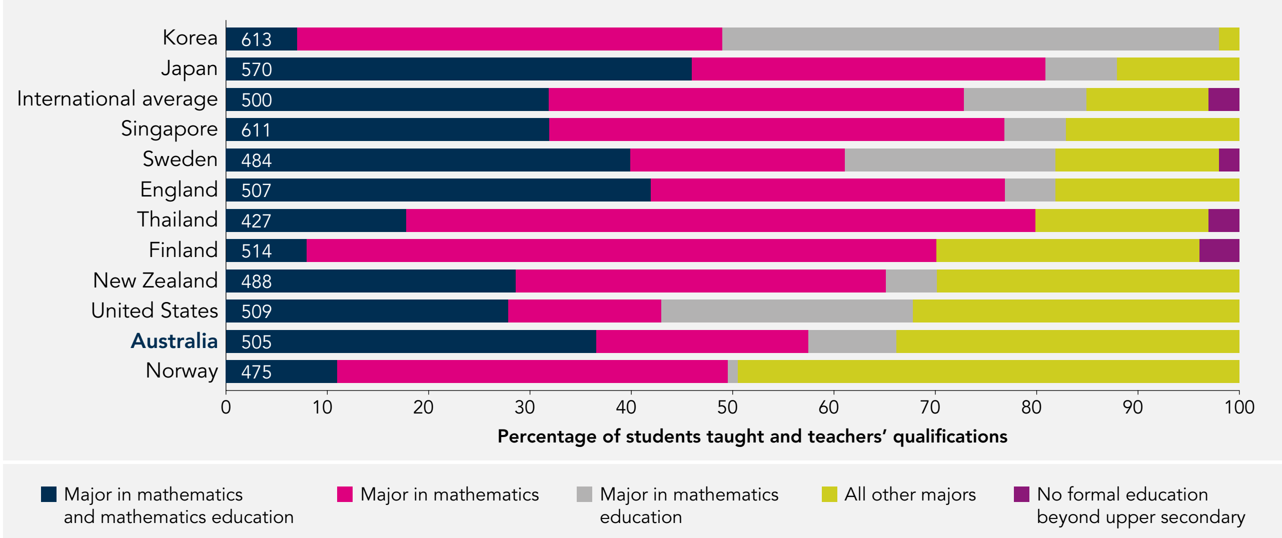
While there is no clear relationship evident from these data between a country's mean mathematics score and the qualifications of its teachers, high-performing nations such as Korea, Japan and Singapore have among the highest proportions of their mathematics teachers having majored in mathematics or mathematics education at university. On the other hand, Sweden also has highly qualified teachers but does not do as well as Australia in tests such as TIMSS. Teacher qualifications are obviously but one part of the story behind national performance in tests such as TIMSS. Having year 8 teachers qualified in either mathematics or mathematics education is, however, certainly a feature of the highest performing nations compared with Australia.

At the year 8 level, 86 per cent of Australian students were taught science by teachers with a major in science or science education, or both (see Figure 9-4). This proportion is similar to the international average.

As with the mathematics teacher preparation data, there is no definitive relationship evident between a country's mean science score and the qualifications of its teachers. As with mathematics, however, high-performing nations such as Singapore, Korea, England and Japan each have a high proportion of their science teachers having majored in science or science education at university. On the other hand, Finland has a similar number of qualified science teachers to Australia but still ranks higher in TIMSS. Again, teacher qualifications for year 8 are but one part of the story behind national performance in tests such as TIMSS.

As noted, in Australia information about teacher qualifications is also collected by ACER through its Staff in Australia's Schools survey, conducted every three years (McKenzie et al. 2011). The latest published data are from the 2010 survey.

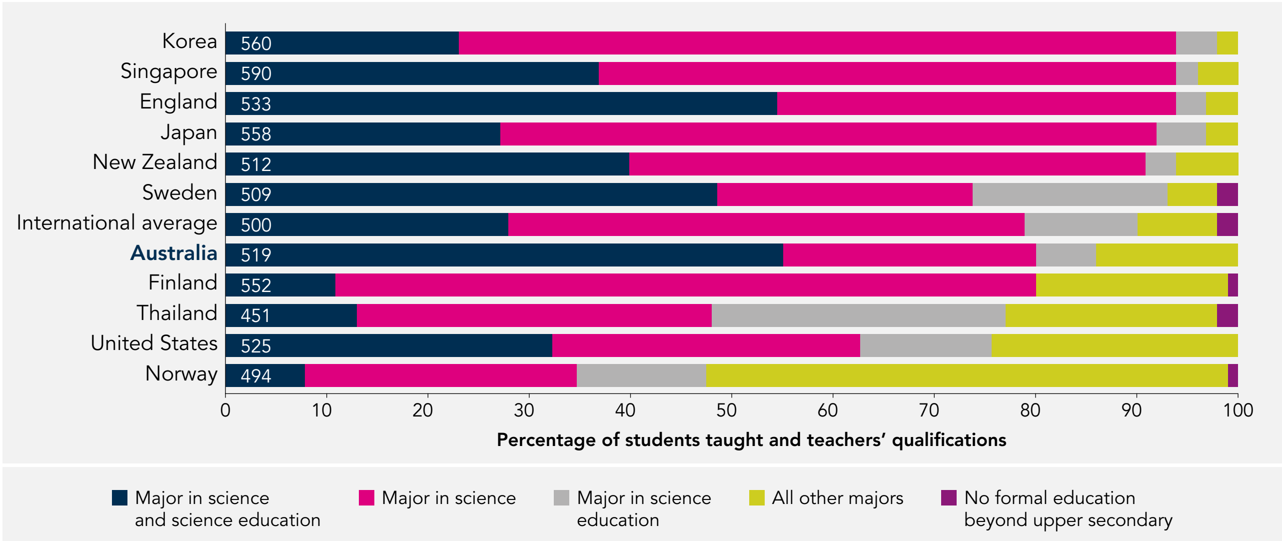
Figure 9-3 Qualifications of teachers teaching mathematics to year 8 students, selected countries, 2011



Notes: Figure shows the proportion of year 8 students who were taught mathematics by teachers holding specific majors. The proportion of teachers within each education category is shown for comparator countries where data were available. The countries are ordered by the proportion of year 8 students taught mathematics by a teacher who had a major in mathematics, a major in mathematics education, or both. The white numbers overlaid show each country's mean score in TIMSS 2011 mathematics achievement (year 8).

Source: TIMSS 2011 international results in mathematics.

Figure 9-4 Qualifications of teachers teaching science to year 8 students, selected countries, 2011



Notes: Figure shows the proportion of year 8 students who were taught science by teachers holding specific majors. The proportion of teachers within each education category is shown for each of the comparator countries. The countries are ordered by the proportion of year 8 students taught science by a teacher who had a major in science, a major in science education, or both. The white numbers overlaid show each country's mean score in TIMSS 2011 science achievement (year 8).

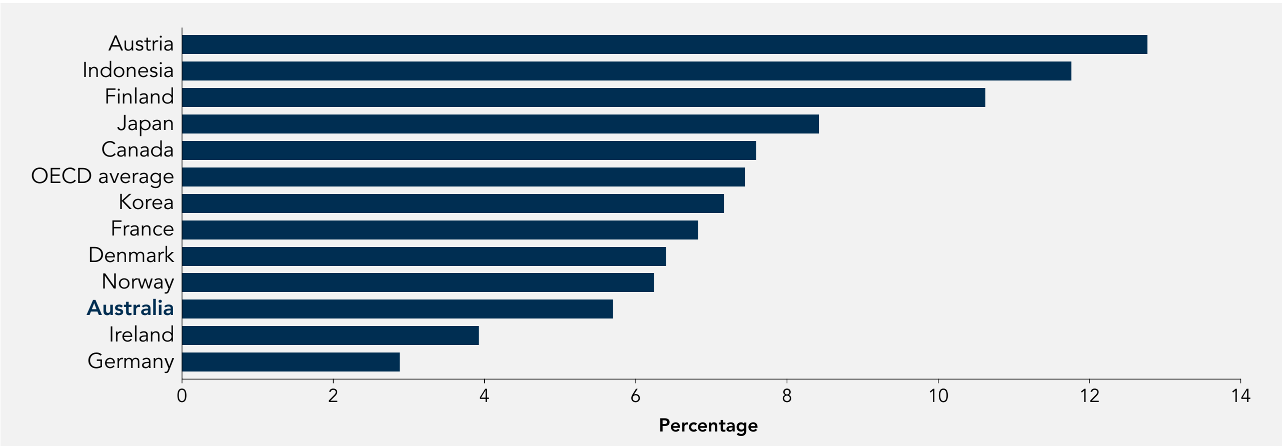
Source: TIMSS 2011 international results in mathematics.

Table 9-3 Australian teachers teaching in selected fields: level of tertiary study in teaching field and training in subject methodology

Field of teaching (school year)	Teachers with some tertiary study in field of teaching at third-year level (%)	Teachers with some tertiary study in field of teaching at second-year level (%)	Teachers with some tertiary study in field of teaching at first-year level (%)	Teachers with methodology training in field of teaching (%)
Mathematics (7/8–10)	46	61	77	60
Mathematics (11–12)	64	81	90	76
Physics (11–12)	54	71	91	57
Chemistry (11–12)	75	90	96	67

Source: ACER, 2010 Staff in Australia's Schools survey.

Figure 9-5 Legislated proportion of time spent teaching science in primary education as a proportion of total compulsory education time, 2011



Note: Figure shows the minimum proportion of time that is expected to be spent teaching science in primary school, as mandated by each country. Data are calculated based on the intended hours of instruction as a proportion of the total intended teaching hours per week during primary school. Differences may exist across countries between the regulated minimum hours of instruction and the actual hours of instruction received by students. Indonesia data included the last three years of primary education only. Denmark data exclude the first year of primary education.

Source: OECD (2011a), ACARA (2013).

Table 9-3 shows the estimated proportions of Australian science and mathematics teachers (for selected secondary school year levels) who have been formally trained in the fields in which they are teaching. Of the teachers who teach mathematics to secondary school students (years 7/8 to 10), 61 per cent have studied mathematics at university to at least second-year level. Of this group, 60 per cent have had formal training in mathematics teaching methodology. The data do not show the extent to which these groups overlap.

Senior school mathematics teachers were more highly qualified as a group. About two-thirds (64 per cent) had studied mathematics at third-year level at university and 76 per cent had studied mathematics teaching methodology. Chemistry and physics teachers in senior secondary school (years 11 and 12) had nearly all studied at least one semester (first-year level) of their teaching subject at university. Only half of senior secondary school physics teachers, however, had studied physics in their third year at university.

9.7 TIME DEVOTED TO TEACHING MATHEMATICS AND SCIENCE

The amount of time spent teaching science and mathematics in schools is another indicator used for benchmarking science and mathematics education in Australian schools.

In 2011 the average time Australian primary students should have been taught science was 5.7 per cent of formal instruction time, which is below the OECD average of 7.4 per cent and below the level for many other comparator countries for which there are data (see Figure 9-5). Although the data are difficult to compare because of different curriculum policies, they nevertheless provide an indication of how much formal instruction time is considered necessary for students to achieve the desired educational goals.

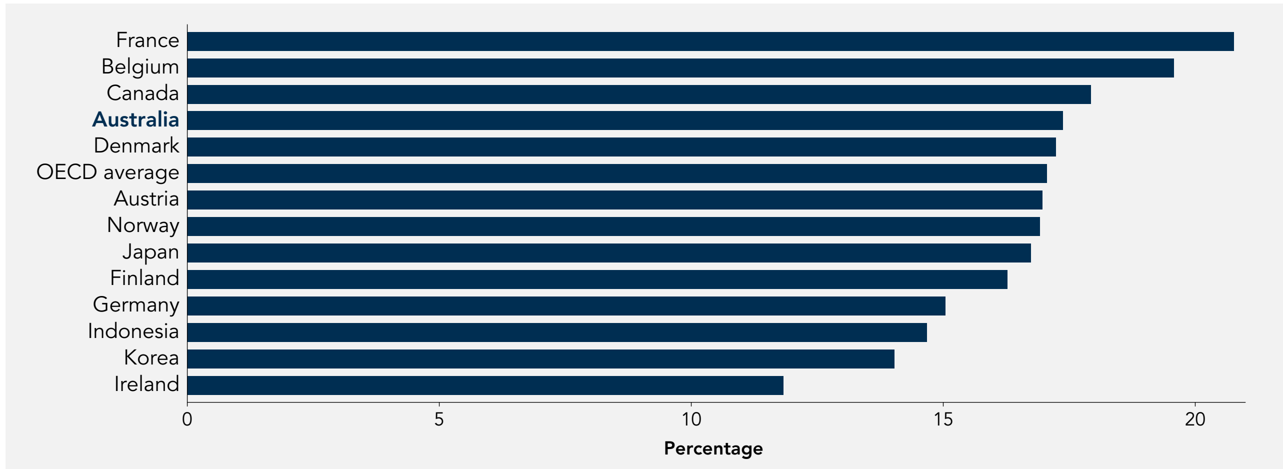
Table 9-4 Indicative teaching time in Australia: science, mathematics and technology as a percentage of total teaching time in primary education

	Year						
Subject	**F**	**1**	**2**	**3**	**4**	**5**	**6**
Mathematics	18	18	18	18	18	16	16
Science	4	4	4	7	7	7	7
Technology	2	2	2	4	4	6	6

Note: F indicates foundation, referring to the year before Year 1.

Source: ACARA.

Figure 9-6 Legislated proportion of time spent teaching mathematics in primary education as a proportion of total compulsory education time, selected countries, 2011



Note: Figure shows the minimum proportion of time that is expected to be spent teaching mathematics in primary school, as mandated by each country. Data are calculated based on the intended hours of instruction as a proportion of the total intended teaching hours per week during primary school. Differences may exist across countries between the regulated minimum hours of instruction and the actual hours of instruction received by students. Indonesia data included the last three years of primary education only. Denmark data exclude the first year of primary education.

Sources: OECD (2013); ACARA.

Table 9-4 shows the recommended indicative teaching hours endorsed by ministers responsible for education in each Australian state and territory.

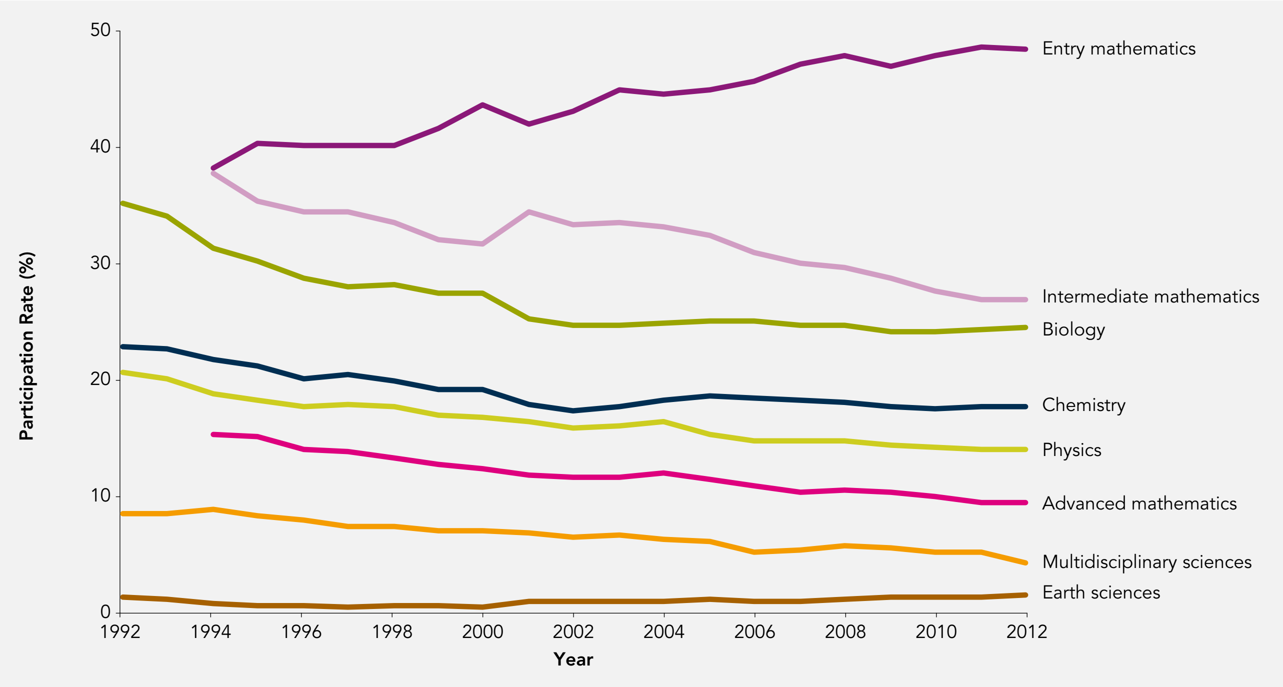
The proportion of time per week that Australian primary students should be taught mathematics is about 17 per cent, which is the same as the OECD average and similar to or higher than the proportion in most comparator countries (see Figure 9-6).

9.8 AUSTRALIAN STUDENTS' PARTICIPATION IN SCIENCE AND MATHEMATICS

The final year of secondary school in Australia offers students the flexibility to choose the subjects they wish to study. Neither science nor mathematics is compulsory: these subjects are offered alongside many other competing subjects.

Numerous school-leaving qualifications are available to Australian students. They are administered by the states and territories and the International Baccalaureate. Each has its own offering of subjects and uses different labels for those subjects (Kennedy et al. 2014). To discern national trends in the study of science and mathematics, it is necessary to combine enrolment data from the various jurisdictions.

Figure 9-7 Participation rates of Australian year 12 student in science and mathematics subjects, 1992 to 2012



Note: Figure shows the number of students taking a course in science or mathematics as a proportion of the total year 12 population (Kennedy et al. 2014). Students can elect to take one or more science subjects and in some jurisdictions one or more mathematics levels and so may be counted more than once.

For science subjects such as chemistry, physics and biology this is relatively straightforward; for mathematics it is more complex, there being several mathematics levels on offer. In the data presented here, Kennedy et al. (2014) have classified mathematics courses into three groups—entry mathematics, which includes subjects that are not designed to lead to further tertiary study; intermediate mathematics, which includes subjects that provide a knowledge base for tertiary studies involving minimal mathematical understanding; and advanced mathematics for subjects that provide a specialised knowledge base for tertiary studies in engineering and the physical sciences.

Participation rates in physics, chemistry and biology have declined in the past two decades (see Figure 9-7). Participation rates in advanced mathematics and intermediate mathematics have also declined, and this has been accompanied by an increase in the participation rate for entry mathematics. These participation rates can be viewed in the context of growing year 12 enrolments across Australia, which have increased from nearly 170 000 in 1995 to 220 000 in 2012.

9.9 CONCLUDING REMARKS

The OECD PISA scores show that 15-year-old Australian school students' performance in mathematics is declining in both absolute and relative terms. From 2003 to 2012 mean PISA scores in mathematics declined and the number of countries performing better than Australia increased. PISA also shows Australian students' proficiency in mathematics is declining, with the proportion of low performers rising and the proportion of top performers falling. In science, Australia's overall PISA score has remained relatively unchanged, as has the proportion of low and top performers each year.

PISA primarily assesses year 10 Australian students, who are at a crucial stage in their secondary education. This is when students are making or will soon make decisions about the subjects they will study in senior secondary school. Their choices will be determined by a complex interplay of factors, including the influence of teachers in their central role of delivering science and mathematics education, what students are able to achieve, and what they feel they are both confident about and interested in. The decline in mathematical literacy in students at this crucial stage is indicative of a growing cohort of students who might struggle to participate fully in a range of life situations and jobs in a modern economy.

APPENDIXES

APPENDIX A

Thomson Reuters InCites publication data were obtained from Web of Science. Web of Science has its own publication classification scheme but, since the aim of this report is to benchmark Australian performance, we chose to use the Australian and New Zealand Standard Research Classification, or ANZSRC, using fields of research. A detailed explanation of the mapping of Web of Science classifications to the ANZSRC for Web of Science publications is provided in the InCites help (Thomson Reuters 2012).

The field of research classification scheme is based on a 2008 report developed by the Australian Bureau of Statistics and Statistics New Zealand and funded in part by the Australian Research Council (www.arc.gov.au/pdf/ANZSRC_FOR_codes). The classification detailed in the ANZSRC document was produced in order to classify and assess the research output of Australia and New Zealand. In 2011 an updated journal list was released for a second round of Excellence in Research for Australia and the Global Comparisons scheme has been updated with this revised mapping.

The field of research scheme is one of three classifications published with the 2008 report. By definition, it allows research and development 'activity to be categorised according to the field of research … it is the method used in the R&D that is being considered'. There are three hierarchy levels in the published FoR classification scheme—division, group and field. Specific classifications in each level are assigned a unique two-digit, four-digit or six-digit code respectively. Using the published codes in the journal title list (www.arc.gov.au/era/era_2012/era_journal_list) in the mapping for Global Comparisons, we mapped two levels—divisions, as FoR Level 1 with two-digit codes, and groups, as FoR Level 2 with four-digit codes (see Table A-1).

The publications, which were classified using the classification contained in the ANZSRC, are not limited to those published in Australia or New Zealand: publication representation is global in scope and is not limited to the English language. In addition, the journal title list includes ISSNs (International Standard Serial Numbers) for each publication, which can refer to a previous title under which that publication had been published.

Web of Science indexes a segment of the journals published globally. Global Comparisons is based on the individual documents published in this pool of publications. To create a mapping between Web of Science–indexed journals and FoR classifications, journal titles and ISSNs for those journals listed in the Australian Research Council journal title list were matched to the publication information for publications indexed in Web of Science. Based on this match, to each Web of Science–indexed journal, the appropriate Excellence in Research for Australia ID (unique publication ID) was assigned and the match between title and ISSN and all FoR category codes was preserved.

In the published journal title list and for each publication, the FoR2 (division) codes are not published where an FoR4 (group) code belonging to a given division already exists. (For example, a publication categorised as belonging to the FoR4 classification Political Science [FoR4="1606"] would not be explicitly categorised into the appropriate FoR2 field, Studies in Human Society [FoR2="16"].) To create the appropriate roll-up, FoR4 codes were truncated and de-duplicated to map journals to an FoR2 classification where no link had previously been explicitly defined. Furthermore, not all journals will be sufficiently specialised to warrant an FoR4 (group) code, so the sum of individual publication counts will not necessarily equal counts of the same at the FoR2 level; all matched publications will be assigned an FoR2 code.

While there is substantial overlap between the two, there are a number of publications in the FoR classifications not included in Web of Science and vice versa. Australian Bureau of Statistics fields of research included in the analysis are 01 to 11. Analysis of field 11 is limited to fields in the Excellence in Research for Australia field cluster Biomedical and Clinical Health Sciences.

Table A-1 ANZSRC Field of Research classifications for STEM fields

FoR	TITLE
01	**MATHEMATICAL SCIENCES**
0101	Pure Mathematics
0102	Applied Mathematics
0103	Numerical and Computational Mathematics
0104	Statistics
0105	Mathematical Physics
0199	Other Mathematical Sciences
02	**PHYSICAL SCIENCES**
0201	Astronomical and Space Sciences
0202	Atomic, Molecular, Nuclear, Particle and Plasma Physics
0203	Classical Physics
0204	Condensed Matter Physics
0205	Optical Physics
0206	Quantum Physics
0299	Other Physical Sciences
03	**CHEMICAL SCIENCES**
0301	Analytical Chemistry
0302	Inorganic Chemistry
0303	Macromolecular and Materials Chemistry
0304	Medicinal and Biomolecular Chemistry
0305	Organic Chemistry
0306	Physical Chemistry (Incl. Structural)
0307	Theoretical and Computational Chemistry
0399	Other Chemical Sciences
04	**EARTH SCIENCES**
0401	Atmospheric Sciences
0402	Geochemistry
0403	Geology
0404	Geophysics
0405	Oceanography
0406	Physical Geography and Environmental Geoscience
0499	Other Earth Sciences

FoR	TITLE
05	**ENVIRONMENTAL SCIENCES**
0501	Ecological Applications
0502	Environmental Science and Management
0503	Soil Sciences
0599	Other Environmental Sciences
06	**BIOLOGICAL SCIENCES**
0601	Biochemistry and Cell Biology
0602	Ecology
0603	Evolutionary Biology
0604	Genetics
0605	Microbiology
0606	Physiology
0607	Plant Biology
0608	Zoology
0699	Other Biological Sciences
07	**AGRICULTURAL & VET SCIENCES**
0701	Agriculture, Land and Farm Management
0702	Animal Production
0703	Crop and Pasture Production
0704	Fisheries Sciences
0705	Forestry Sciences
0706	Horticultural Production
0707	Veterinary Sciences
0799	Other Agricultural and Veterinary Sciences
08	**INFORMATION & COMPUTING SCIENCES**
0801	Artificial Intelligence and Image Processing
0802	Computation Theory and Mathematics
0803	Computer Software
0804	Data Format
0805	Distributed Computing
0806	Information Systems
0807	Library and Information Studies
0899	Other information and computing sciences

FoR	TITLE
09	**ENGINEERING**
0901	Aerospace Engineering
0902	Automotive Engineering
0903	Biomedical Engineering
0904	Chemical Engineering
0905	Civil Engineering
0906	Electrical and Electronic Engineering
0907	Environmental Engineering
0908	Food Sciences
0909	Geomatic Engineering
0910	Manufacturing Engineering
0911	Maritime Engineering
10	**TECHNOLOGY**
1005	Communications Technologies
1006	Computer Hardware
1007	Nanotechnology
1099	Other Technology
11	**MEDICAL AND HEALTH SCIENCES**
	Biomedical and Clinical Health Sciences
1101	Medical Biochemistry and Metabolomics
1102	Cardiovascular Medicine and Haematology
1103	Clinical Sciences
1105	Dentistry
1107	Immunology
1108	Medical Microbiology
1109	Neurosciences
1112	Oncology and Carcinogenesis
1113	Ophthalmology and Optometry
1114	Paediatrics and Reproductive Medicine
	Public and Allied Health
1104	Complementary and Alternative Medicine
1106	Human Movement and Sports Science
1110	Nursing
1111	Nutrition and Dietetics
1117	Public Health and Health Services
1118	Other Medical and Health Sciences

APPENDIX B

B.1 CHARACTERISTICS OF THE STEM WORKFORCE

The Office of the Chief Scientist commissioned the Australian Bureau of Statistics (ABS) to undertake a series of projects to understand the characteristics of the STEM workforce. Analyses here explore the range of industries, occupations and salaries held by STEM graduates in Australia. It also presents data on the impact of employed STEM graduates on innovation.

B.2 METHOD AND DATA SOURCES

B.2.1 Analyses of the STEM Workforce

The data in Figure B-1 are drawn from the ABS Survey of Learning and Work, conducted from July 2010 to June 2011 as part of the ABS Multipurpose Household Survey. The survey collected data from individuals about their "non-school qualification" history.

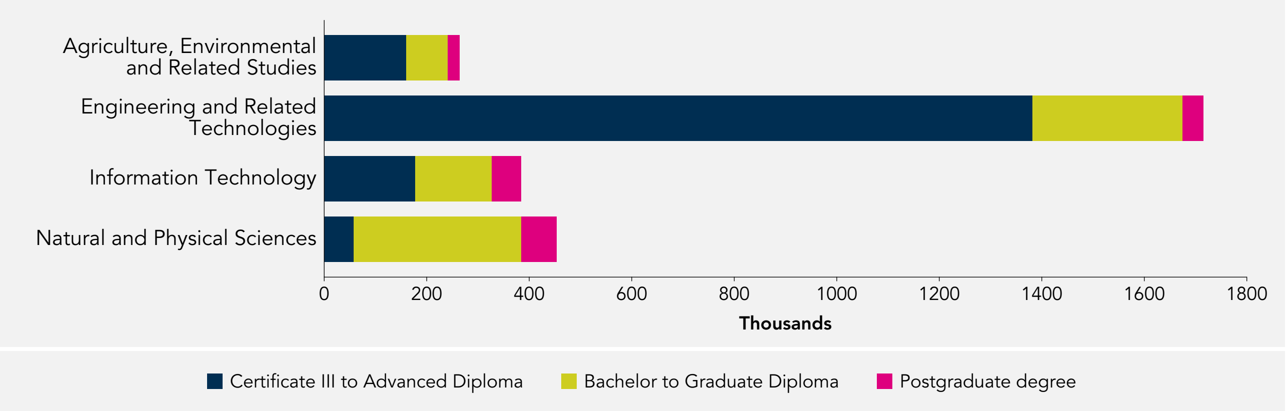
The data for Figure B-2 to Figure B-16 are derived from the 2011 Census of Population and Housing and includes people whose highest non-school qualification was in a STEM field holding a qualification of a bachelor degree or above. The number of respondents indicated under each figure does not include responses which were inadequately described, not stated or not applicable. The charts present the industries and occupations that employ 75 per cent of the STEM graduate workforce.

For the purpose of these analyses, STEM qualifications are defined according to the Australian Standard Classification of Education, 2001, as those in the fields of:

- Natural and physical sciences (including mathematical sciences)
- Information technology
- Engineering and related technologies
- Agricultural, environmental and related studies

Where data are presented by industry sector, these are specified at the two-digit level of the Australian and New Zealand Standard Industrial Classification, 2006 version. For example, professional, scientific and technical services is a one-digit (Division) level of the ANZSIC and within it, computer system design and related services, is the two-digit subdivision. The field of qualification follows the Australian Standard Classification of Education, 2001 and is provided at the one-digit level (for example natural and physical sciences).

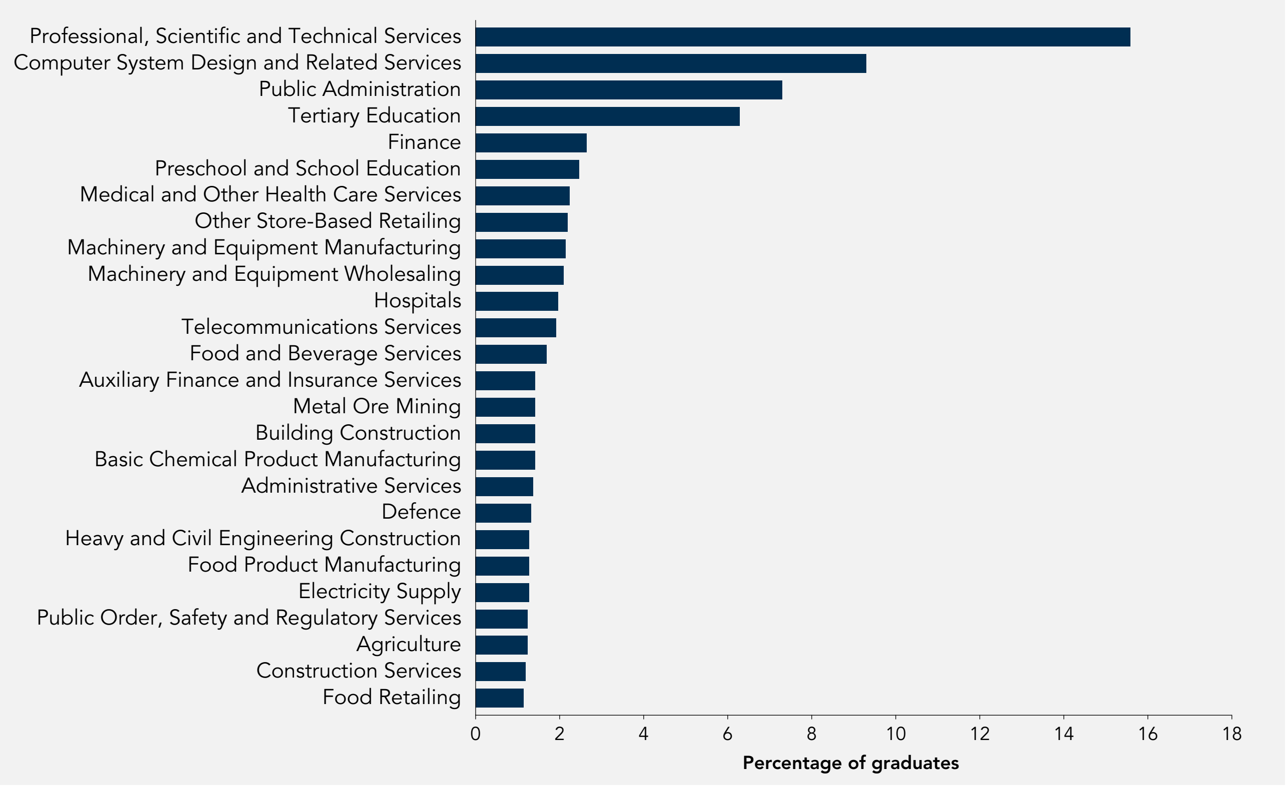
Figure B-1 Highest qualification by field and level, 2010–11



Notes: These population data are based on a sample of 13 366 fully responding households, which represented a response rate of 78 per cent. Data cover all persons aged 15 and above.

Source: ABS (2012c).

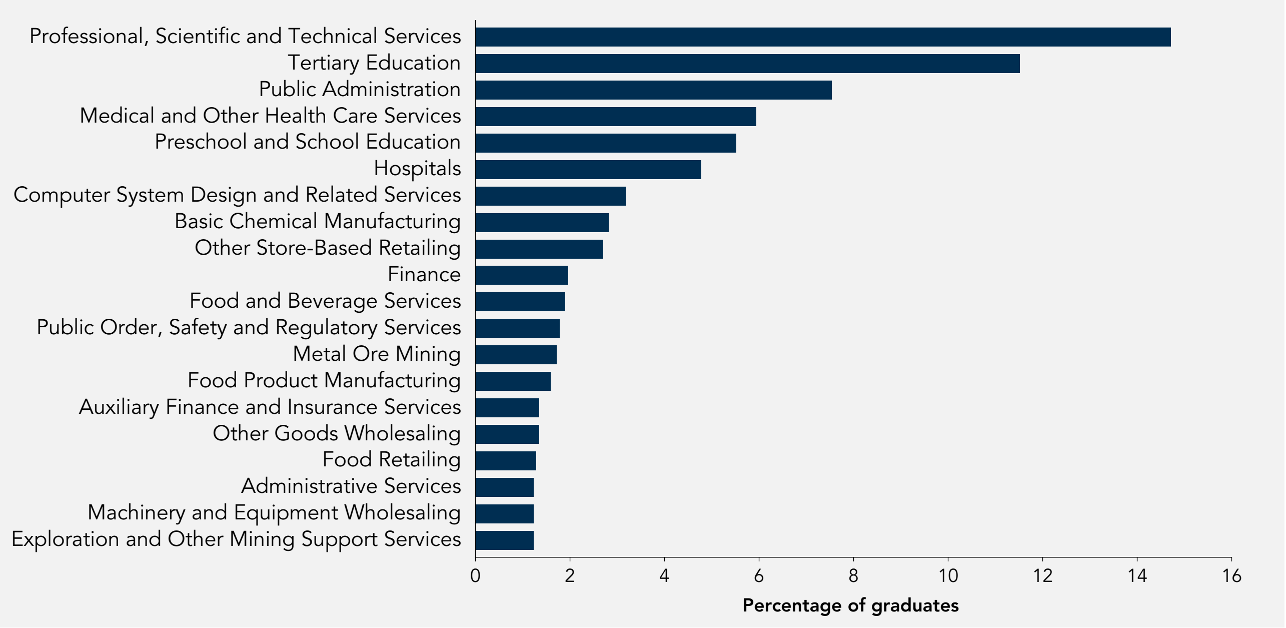
Figure B-2 STEM graduates (bachelor and above) by industry of employment, 2011



Notes: The total number of respondents was 557 834. Professional, scientific and technical services (except computer system design and related services) and basic chemical and chemical product manufacturing industries have been abbreviated.

Source: ABS (2011).

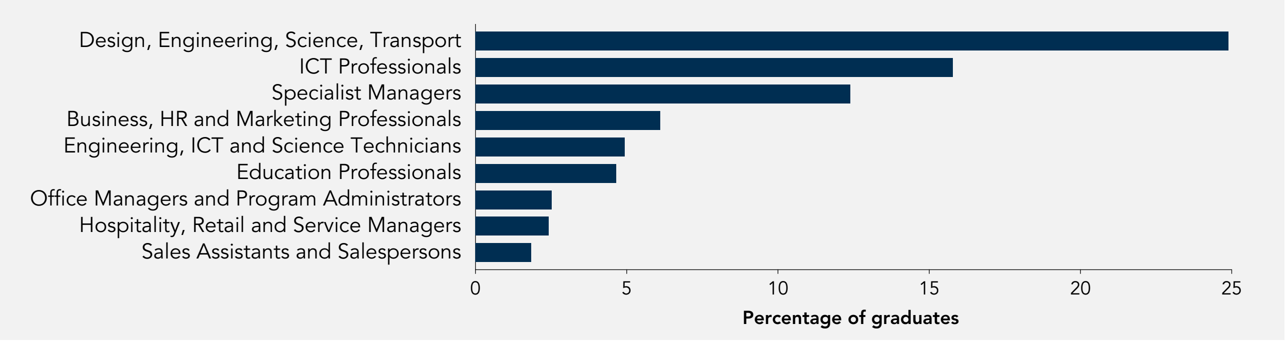
Figure B-3 Natural and physical science graduates (bachelor and above) by industry of employment, 2011



Notes: The total number of respondents was 172 482. Professional, scientific and technical services (except computer system design and related services) and basic chemical and chemical product manufacturing industries have been abbreviated.

Source: ABS (2011).

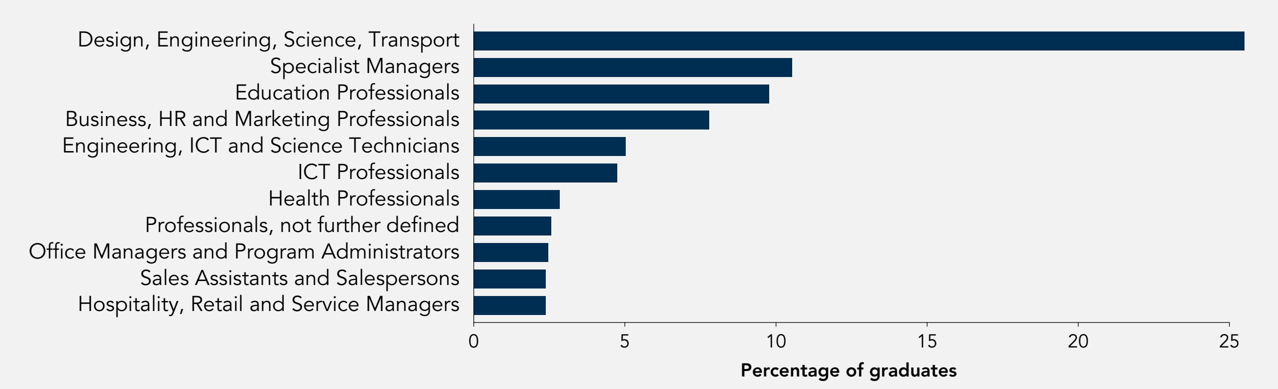
Figure B-4 STEM graduates (bachelor and above) by occupation, 2011



Notes: The total number of respondents was 557 979. Design, engineering, science and transport professionals has been abbreviated.

Source: ABS (2011).

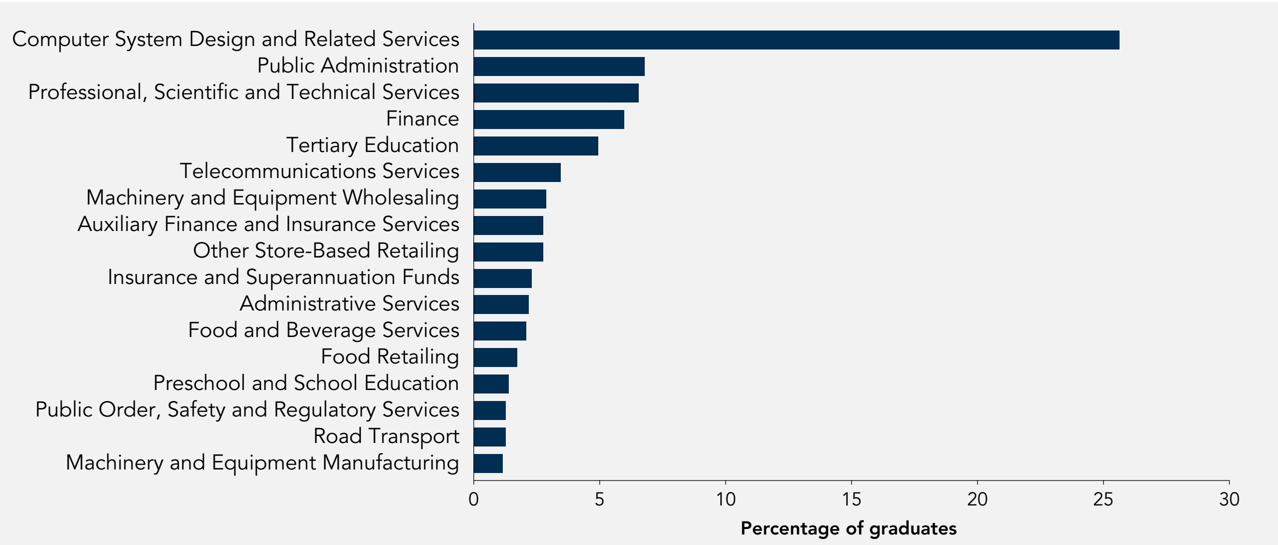
Figure B-5 Natural and physical science graduates (bachelor and above) by occupation, 2011



Notes: The total number of respondents was 172 574. Design, engineering, science and transport professionals has been abbreviated. Professionals not further defined refers to occupations that could not be assigned to a specific occupational category within the broader (major) category of professionals but is known to be an occupation in the professionals category.

Source: ABS (2011).

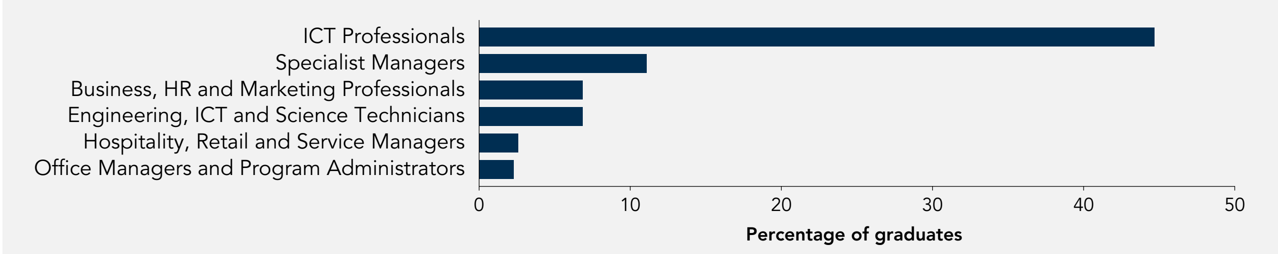
Figure B-6 Information Technology graduates (bachelor and above) by industry of employment, 2011



Notes: The total number of respondents was 136 064. Professional, scientific and technical services (except computer system design and related services) has been abbreviated.

Source: ABS (2011).

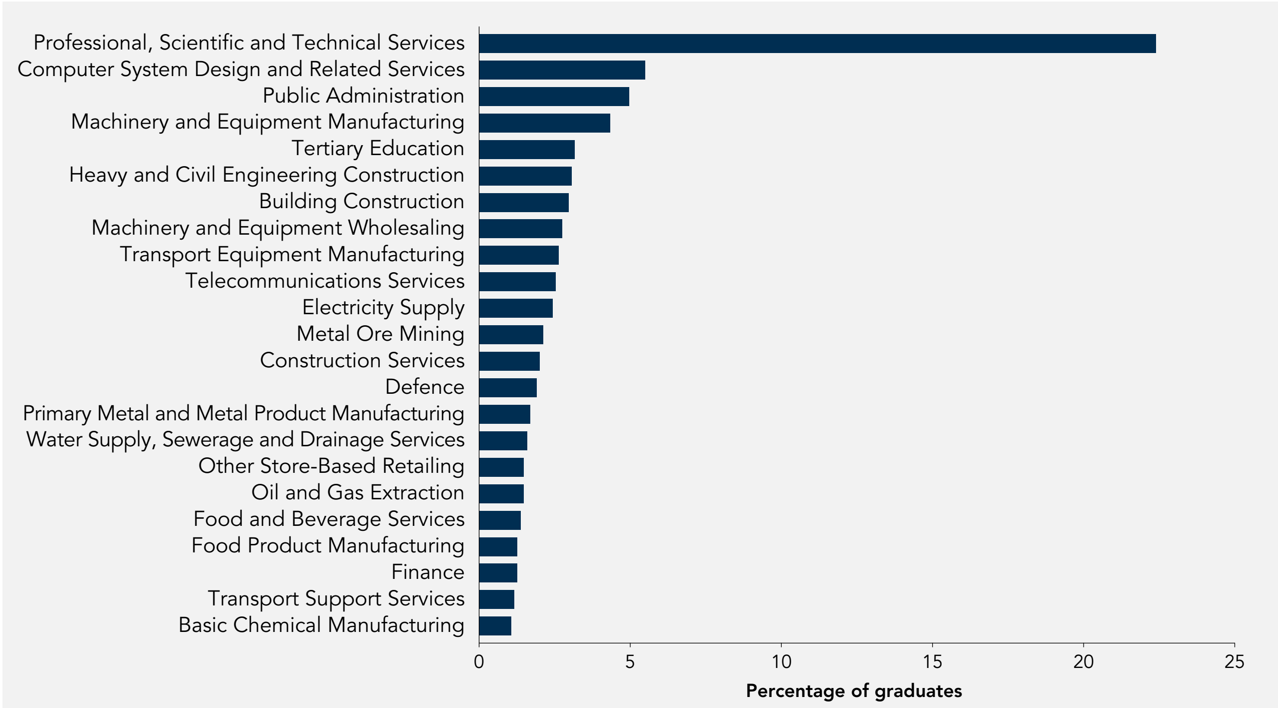
Figure B-7 Information Technology graduates (bachelor and above) by occupation, 2011



Notes: The total number of respondents was 135 245.

Source: ABS (2011).

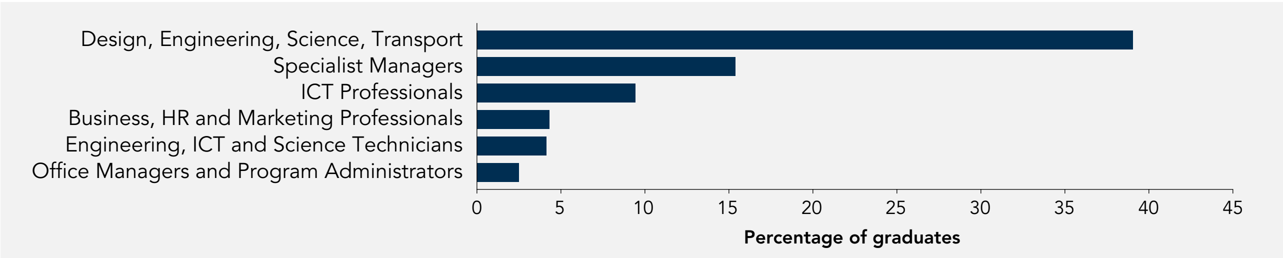
Figure B-8 Engineering and related technologies graduates (bachelor and above) by industry of employment, 2011



Notes: The total number of respondents was 206 545. Professional, scientific and technical services (except computer system design and related services) has been abbreviated.

Source: ABS (2011).

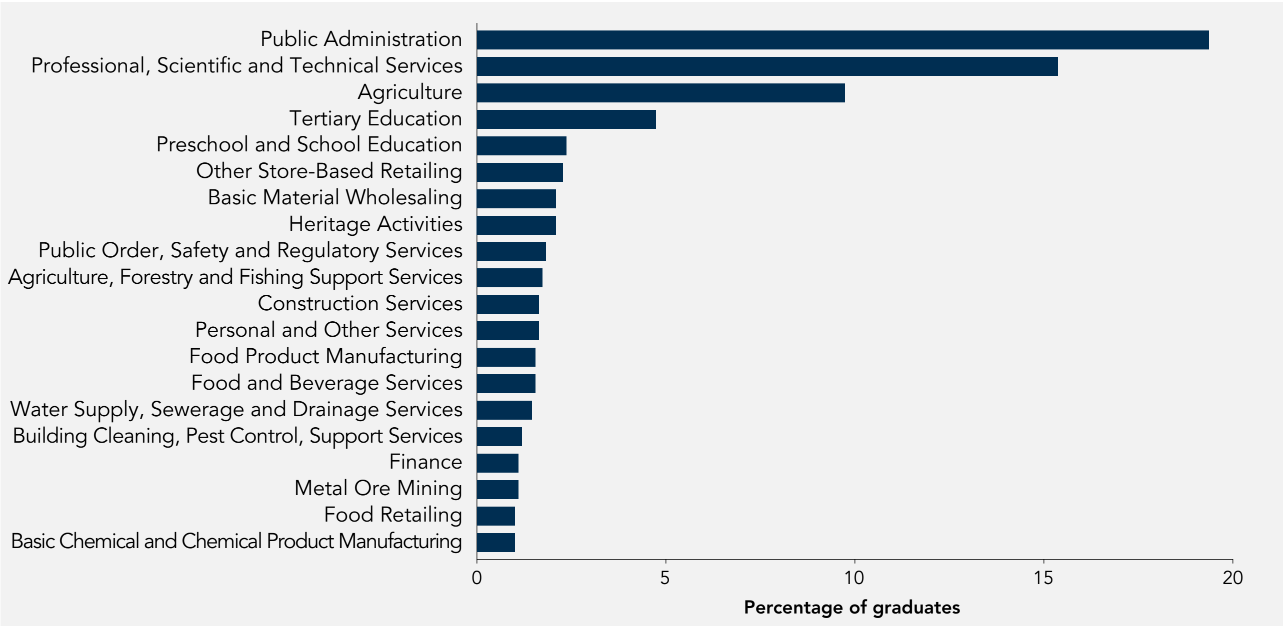
Figure B-9 Engineering and related technologies graduates (bachelor and above) by occupation, 2011



Notes: The total number of respondents was 207 467. The category Design, engineering, science and transport professionals has been abbreviated.

Source: ABS (2011).

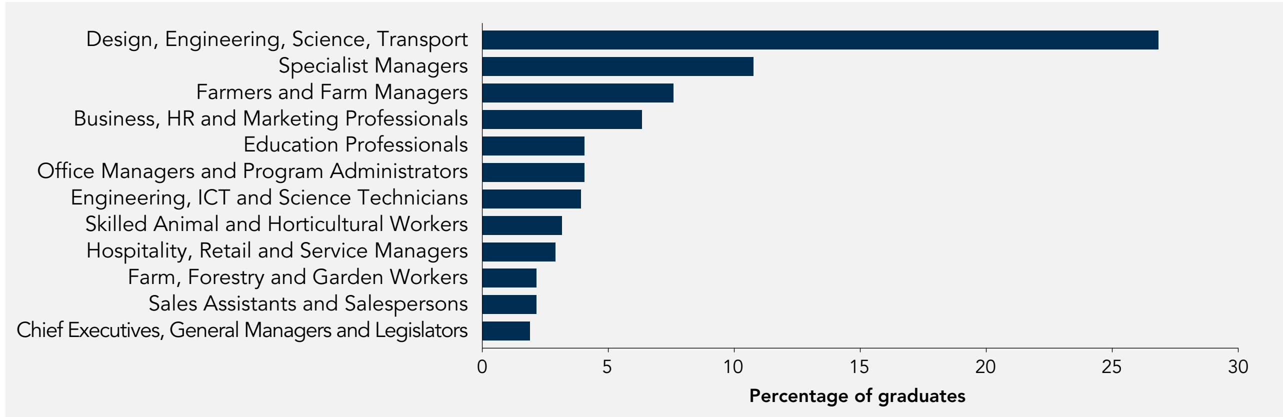
Figure B-10 Agriculture, environmental and related studies graduates (bachelor and above) by industry of employment, 2011



Notes: The total number of respondents was 42 743. Professional, scientific and technical services (except computer system design and related services) has been abbreviated.

Source: ABS (2011).

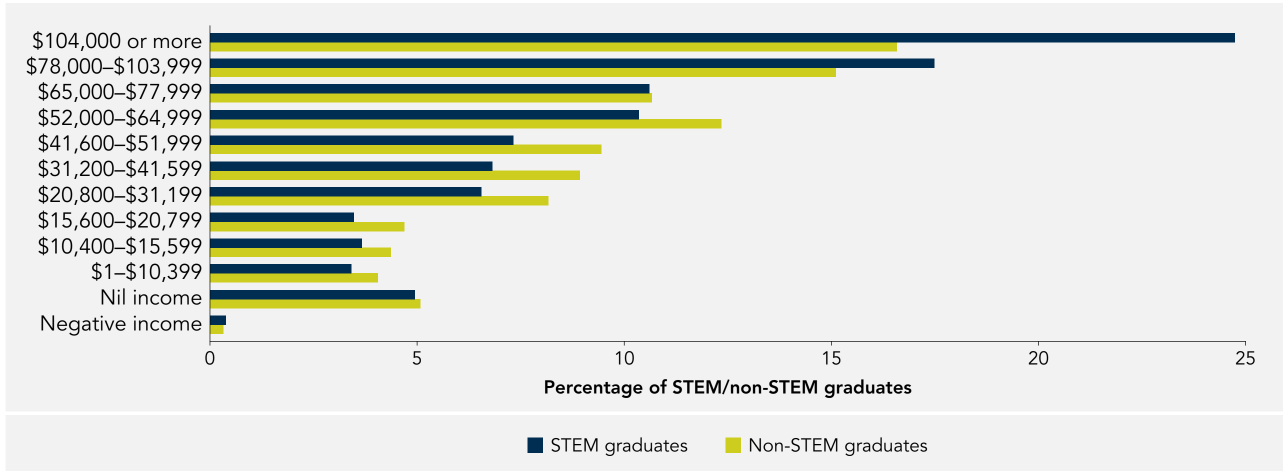
Figure B-11 Agriculture, environmental and related studies graduates (bachelor and above) by occupation, 2011



Notes: The total number of respondents was 42 693. Design, engineering, science and transport professionals has been abbreviated.

Source: ABS (2011).

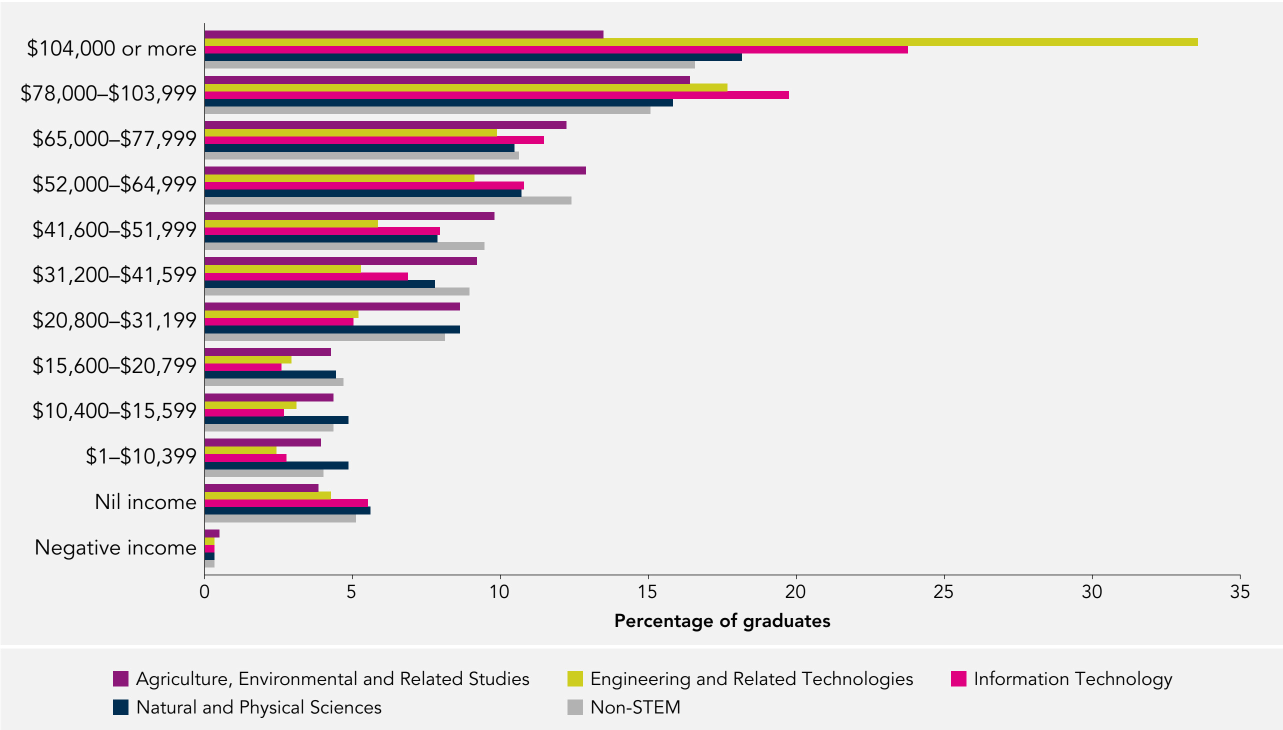
Figure B-12 Salaries of STEM graduates (bachelor and above), 2011



Notes: The total number of respondents was 697 483.

Source: ABS (2011).

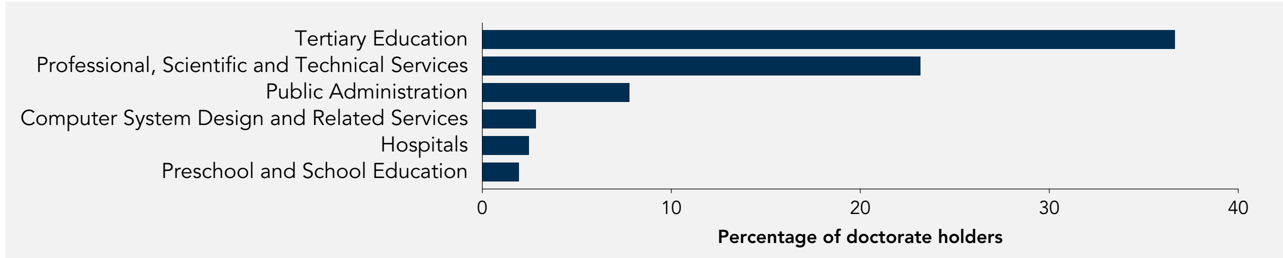
Figure B-13 Salaries of STEM and non-STEM graduates by field of qualification (bachelor and above), 2011



Notes: A total of 697 483 STEM graduates and 2 535 800 non-STEM graduates responded.

Source: ABS (2011).

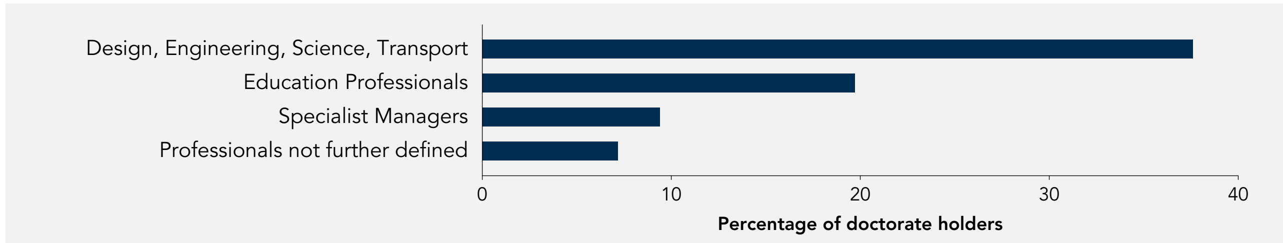
Figure B-14 STEM doctorate holders by industry of employment, 2011



Notes: The total number of respondents was 42 440. Professional, scientific and technical services (except computer system design and related services) has been abbreviated.

Source: ABS (2011).

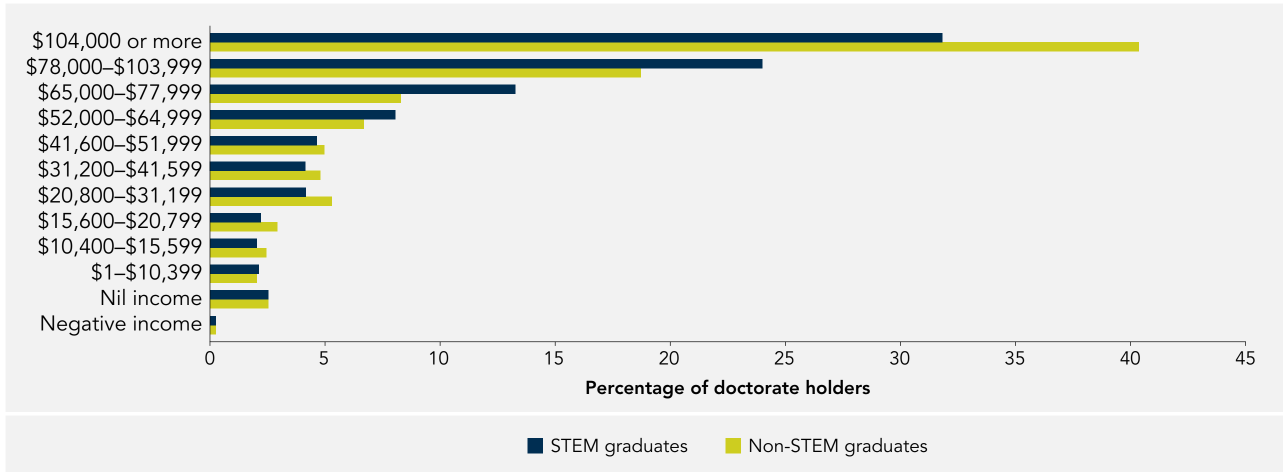
Figure B-15 STEM doctorate holders by occupation, 2011



Notes: The total number of respondents was 42 414. Professionals not further defined refers to occupations that could not be assigned to a specific occupational category within the broader (major) category of professionals but is known to be an occupation in the professionals category. Design, engineering, science and transport professionals has been abbreviated.

Source: ABS (2011).

Figure B-16 Salaries of STEM doctorate holders, 2011



Notes: A total 52 925 STEM and 62 194 non-STEM doctorate holders responded.

Source: ABS (2011).

SHORTENED FORMS

SHORTENED FORMS

ABS	Australian Bureau of Statistics
ACARA	Australian Curriculum, Assessment and Reporting Authority
ACER	Australian Council for Educational Research
ANSZCO	Australian and New Zealand Standard Classification of Occupations
ANZSRC	Australian and New Zealand Standard Research Classification
APA	Australian Postgraduate Award
ARC	Australian Research Council
ASCO	Australian Standard Classification of Occupations
BCH	biomedical and clinical health sciences
BERD	business expenditure on research and development
CRC	cooperative research centre
DIBP	Department of Immigration and Border Protection
EFTSL	equivalent full-time student load
EPO	European Patent Office
ERA	Excellence in Research for Australia
EU15	Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, and the United Kingdom
FoR	field of research
FTE	full-time equivalent
GDP	gross domestic product
GERD	gross expenditure on research and development
GFC	global financial crisis
GOVERD	government expenditure on research and development
HDR	higher degree research
HECS	Higher Education Contribution Scheme
HERD	higher education expenditure on research and development
ICT	information and communications technology; information and computing technology
ISSN	International Standard Serial Number
ISCED	International Standard Classification of Education
IT	information technology
MSTI	Main Science and Technology Indicators
N&PS	natural and physical sciences
nec	not elsewhere classified
OECD	Organisation for Economic Co-operation and Development
PCT	Patent Cooperation Treaty
PhD	Doctor of philosophy
PIRLS	Progress in International Reading Literacy Study
PISA	Programme for International Student Assessment
RTS	Research Training Scheme
R&D	research and development
STEM	science, technology, engineering and mathematics
TIMSS	Trends in International Mathematics and Science Study
UK	United Kingdom
UNESCO	United Nations Educational, Scientific and Cultural Organization
US	United States
UWA	University of Western Australia
VET	vocational education and training

GLOSSARY

GLOSSARY

Applied Research	Original work done primarily to acquire new knowledge with a specific application in view. It is done either to determine possible uses for the findings of basic research or to determine new ways of achieving some specific and predetermined objectives.
Bachelor degree	A bachelor degree qualifies individuals who apply a broad and coherent body of knowledge in a range of contexts to undertake professional work and as a pathway for further learning. The volume of learning of a bachelor degree is typically 3–4 years.
Bibliometrics	Bibliometrics involve the application of quantitative analysis and statistics to publications such as journal articles and their accompanying citation counts. Bibliometric analyses of peer-reviewed publications provide insights into how research findings are shared, and credited by other researchers and how they influence the global research effort.
Capital Expenditure	Measures the value of purchases of fixed assets, i.e. those assets that are used repeatedly in production processes for more than a year. The value is at full cost price. Sales of fixed assets are not deducted.
Citation	The formal acknowledgment of intellectual debt to previously published research.
International co-authorship	The proportion of the papers authored by the country that contain a co-author from another country. This is an indicator of the country's ability to collaborate in a global environment.
Comparator countries	Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Norway, Sweden, Switzerland, the United Kingdom, China, India, Indonesia, Japan, Malaysia, the Philippines, Singapore, South Korea, Thailand, Vietnam, the United States, Canada and New Zealand.
Completion	When students satisfy the requirements of their course and graduate they are counted as completions.
Doctorate	The Doctoral Degree qualifies individuals who apply a substantial body of knowledge to research, investigate and develop new knowledge, in one or more fields of investigation, scholarship or professional practice. The volume of learning of a Doctoral Degree is typically 3–4 years.
Experimental development	Systematic work, using existing knowledge gained from research or practical experience, that is directed to producing new materials, products or devices, installing new processes, systems and services, or substantially improving those already produced or installed.
Field-weighted citation rate	A measure of the actual citations received compared with the citations expected on the basis of the average of the field.
Higher education	Students enrol in higher education courses, which are offered at different levels. Typical course levels include entry-level undergraduate courses such as a bachelor's degree and higher, research-based degrees such as the PhD (doctorate).

Innovation	The implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations.
Patent	A right granted by a government to an inventor in exchange for the publication of the invention; it entitles the inventor to prevent any third party from using the invention in any way, for an agreed period.
Pure basic research	Experimental and theoretical work done in order to acquire new knowledge without looking for long-term benefits other than the advancement of knowledge.
Research and development	A term covering three activities: basic research, applied research, and experimental development.
Research Intensity	Research intensity refers to R&D expenditure as a share of gross domestic product.
Researcher	Professional engaged in the conception or creation of new knowledge, products, processes, methods, and systems, and in the management of the projects concerned.
Standard patent	An Australian standard patent gives long-term protection and control over an invention in Australia. It lasts for up to 20 years from the complete application filing date (or up to 25 years for pharmaceutical substances).
STEM	Science, Technology, Engineering and Mathematics.
Strategic basic research	Experimental and theoretical work done in order to acquire new knowledge directed into specified broad areas in the expectation of useful discoveries. It provides the broad base of knowledge necessary for the solution of recognised practical problems.
The Melbourne Model	In 2008 the University of Melbourne introduced major changes to the structure of its undergraduate STEM programs. Under the new model the number of separate bachelor's degrees offered at the university was reduced and students who wanted eventually to qualify eventually in a specific vocational field such as engineering or medicine would first need to complete a bachelor's degree in science.
Triadic patent family	A set of patent applications filed at the European Patent Office and the Japanese Patent Office, and granted by the United States Patent and Trademark Office, sharing one or more priority applications.

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