Research, Science and Innovation System Performance Report

2018

MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
HĪKINA WHAKATUTUKI

New Zealand Government

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Minister's foreword

The Government's vision for New Zealand puts the long-term wellbeing of people and the environment at its centre. Our priorities are reducing child poverty, access to affordable, healthy homes, opportunities for meaningful work, and a just transition to a sustainable, low-emissions economy.

The Government has set a target of raising economy-wide R&D investment to two per cent of GDP over ten years. Research, science and innovation will be a key lever to achieve our goals.

In order to get the most from research, science and innovation and to make investment decisions, we need to understand how the science system is performing. The 2018 Research, Science and Innovation System Performance Report shows some of New Zealand's science and innovation strengths, as well as the scale of the challenge to raise our performance and research investment levels to that of other small advanced economies.

The Government is developing a strategy for future research, science and innovation investment, in support of our wellbeing goals and the two per cent target. I would encourage research, science and innovation sector stakeholders to draw on this report as part of a shared evidence basis when engaging with the Government on the draft strategy.

It is through research, science and innovation that we will generate the new ideas, skills and knowledge to transform the way we live and work, and our planet.

Hon Dr Megan Woods

Minister of Research, Science and Innovation

October 2018

Introduction

ABOUT THIS REPORT

This document is the second in a regular series, on research, science and innovation in New Zealand. The first was published in 2016. The report shows how the New Zealand research, science and innovation system is performing in key areas. This series covers people, skills, funding, the knowledge produced and the impacts for New Zealand.

New Zealand invests in research, science and innovation because they are fundamental to improving the wellbeing of New Zealanders across multiple domains: economic, environmental, social and cultural. The evidence from OECD countries shows that new knowledge production and innovation are key contributors to economic growth and social progress in the long-term.

This series of reports is intended to be a resource for the many people and institutions who contribute to the performance of the research, science and innovation system. The reports seek to:

- Increase transparency and provide a central, reliable source of data on the system;
- Report on progress against government goals;
- Highlight strengths, weaknesses, and opportunities in order to stimulate discussion among policymakers, funders, researchers and research users.

NEW FEATURES IN THIS REPORT

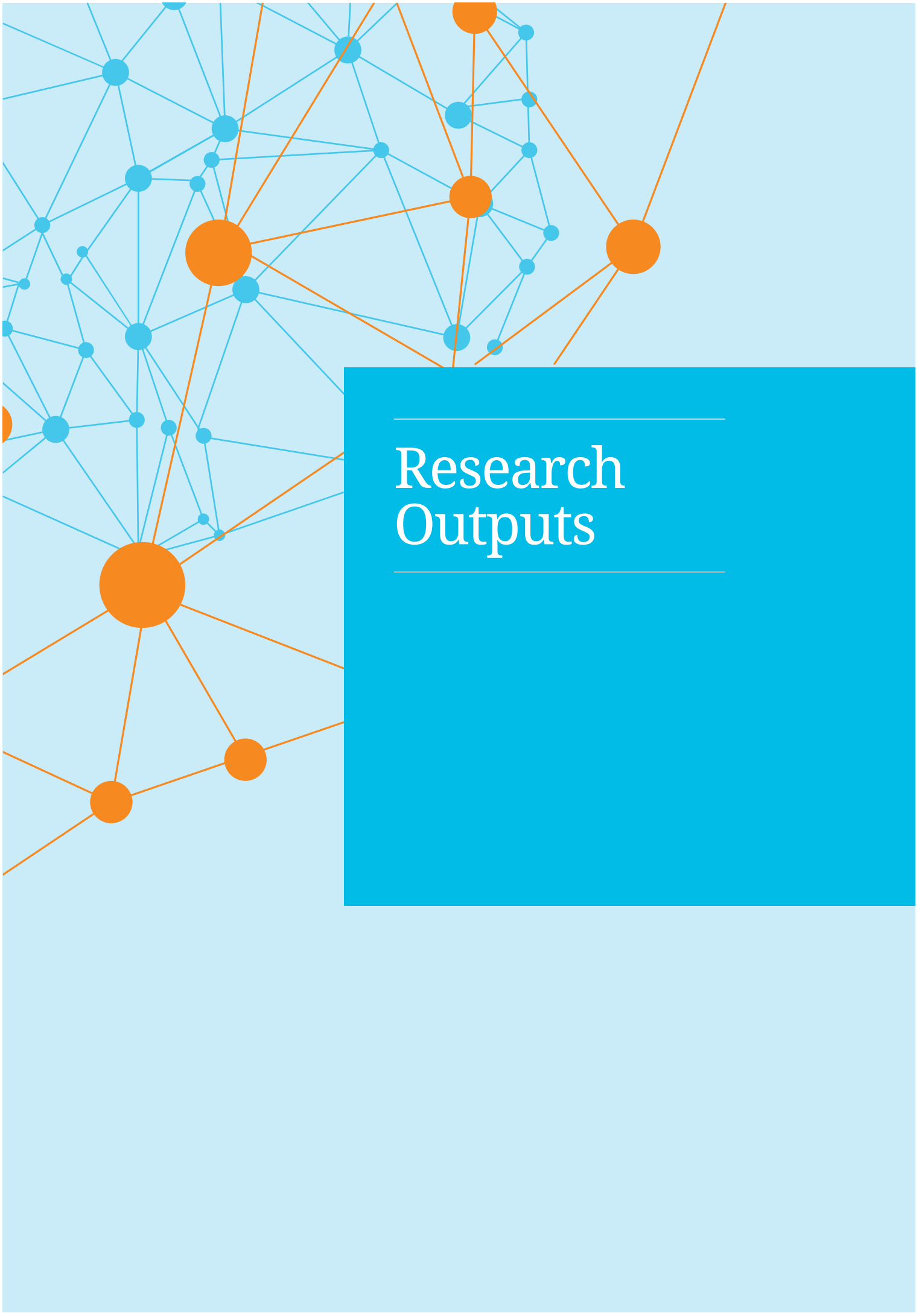
This report updates core indicators from the last report, adding some new data and analysis covering:

- New Zealand's start-up ecosystem;
- Collaboration patterns between research institutions;
- International comparisons of innovation rates; and
- The link between academic citations and patents.

KEY FINDINGS

- **Research productivity:** New Zealand continues to perform very well on research publications per research dollar, at around three-times the OECD average. This is due to a combination of higher productivity per researcher and lower costs per researcher.
- **Research quality:** New Zealand's overall performance on citation-based indicators of research quality remains ahead of the OECD, but largely behind the other Small Advanced Economies and Australia. Agricultural and Biological Science remains our largest research specialism, i.e. the field in which we publish the most above the global average. Medicine is the area in which we publish our most highly-cited research. A relatively high proportion of New Zealand Arts and Humanities research has some influence (66 per cent) with at least one citation.
- **Research expenditure:** Total expenditure on R&D (economy-wide) rose to $3.1b or 1.23 per cent of GDP in 2016, from 1.15 per cent in 2014. This is driven by significant growth in business R&D expenditure, which increased by $356m (29 per cent) between 2014 and 2016, with the majority of the increase (83 per cent) funded by New Zealand businesses.
- **Public funding:** Total public support for research, science and innovation was $1.6b in 2017/18, and is projected to rise to around $2b by 2020, driven by the expected introduction of a R&D tax incentive in 2019. The Strategic Science Investment Fund and Endeavour Fund are currently the largest public research funding mechanisms, investing a total of $448m in 2017/18. The Performance Based Research Fund provides a further $315m to incentivise high-quality research and research-led teaching and learning in tertiary education institutions.
- **Innovation and productivity:** New Zealand's economic productivity continues to lag its peers. According to the OECD and the Treasury, low R&D investment and innovation rates appear to be important factors behind New Zealand's low economic productivity. Strong business R&D investment coupled with a developing start-up ecosystem suggests system-change in this area. Increased business R&D was driven by higher average investment per firm in computer services and manufacturing.

- **Start-up ecosystem:** This report introduces new data on the New Zealand start-up ecosystem. Investment in New Zealand start-up companies has quadrupled over ten years from an estimated $21m and 30 deals in 2006, to $87m and 111 deals in 2017. New Zealand is ahead of Australia and Denmark in terms of estimated venture capital investment as a proportion of GDP. The ICT sector attracted the most early stage investment, estimated at $38m.
- **Impact case studies:** The report includes five case studies on some broad impacts of the New Zealand science and innovation system, from ryegrass and intensive care treatment to space rockets. These allow us to understand how research and skills investment has led to long-term benefits to New Zealand.
- **Workforce:** The number of researchers in New Zealand has increased by 40 per cent between 2006 and 2016. New Zealand has a similar proportion of researchers in the workforce to the OECD average. Researcher FTEs grew from 17,900 to 18,700 between 2014 and 2016, driven by more researchers in business, and more student researchers in higher education.
- **Diversity:** There is a consistent trend of about 20 per cent more female than male doctoral degree completions, but we don't have good data on the overall make-up of the scientific workforce. In terms of ethnicity, Māori are a particularly under-represented ethnic group among doctoral degree completions (7 per cent versus around 15 per cent of the general population).
- **Collaboration:** Overall the rate of international collaboration is continuing to rise in New Zealand and in the Small Advanced Economies and OECD. With over 50 per cent of papers having international co-authorship, New Zealand researchers are relatively well connected to global research. Academic-business collaboration remains relatively low, with only 1.5 per cent of publications having academic-business co-authorship and 4.6 per cent of higher education research funded by business in 2016. There is significant domestic collaboration among universities and Crown Research Institutes (CRIs), with collaborations between Auckland and Canterbury universities producing some of the highest-cited outputs.



Research Outputs

06

Research Outputs

Outputs, such as research publications embody and communicate the new knowledge generated through the research process. By tracking their volume and influence in the global academic community, we can understand more about the quality and efficiency of the research system and where New Zealand's specialisms lie.

In this section of the report research publications include articles, reviews and conference papers only*.

Journal articles, conference proceedings and reviews are key outputs for which we have good data. Other outputs exist, such as books, datasets, intellectual property, client reports (eg CRIs produce around 1,500 to 2,000 of these each year), designs, tools, websites and newspaper articles. However, good quality data at a country level on these output types is not yet available.

* Global research publication databases include a broader range of publication types, such as letters and editorials. We have excluded those from this and other measures in the report because they are smaller in number and it is less clear to what extent they constitute research.

Our science system is relatively small...

Proportion of GDP spent on R&D (latest available data)

...but highly productive

Publications per $m higher education and government research expenditure

NZ 13

OECD 5

Publications per researcher per year

NZ 0.7

OECD 0.3

We have some research specialisations

Top 3

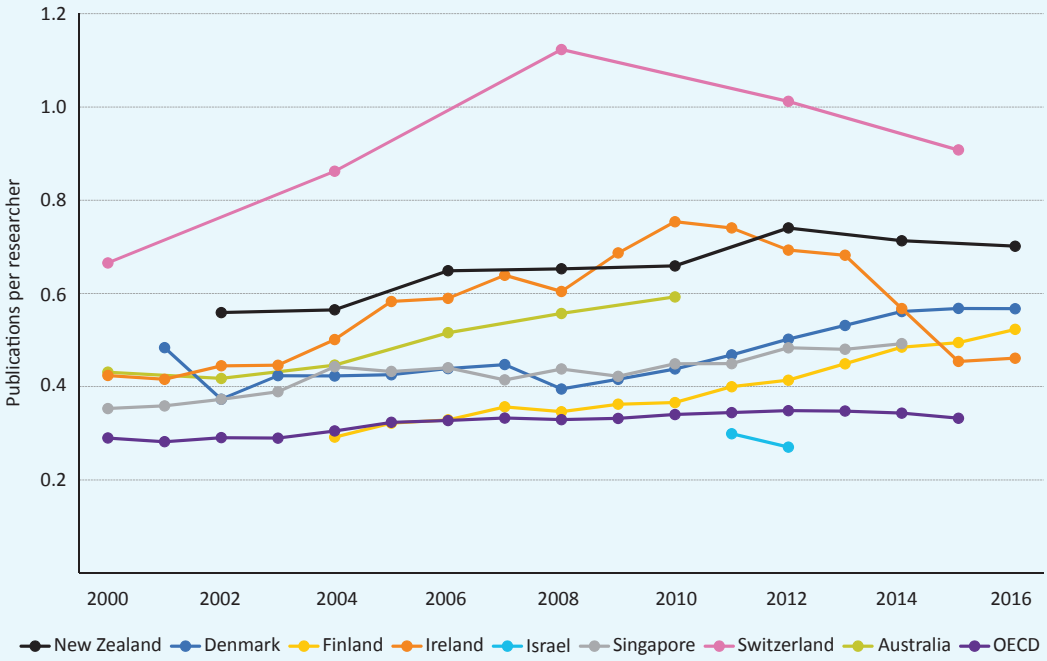
Research specialities in terms of relative publication volume

- Agriculture and Biological Sciences
- Business, Management and Accounting
- Health Professions

PUBLICATION PER RESEARCHER†

This is the total number of research publications divided by the total number of researchers in a country.

Figure 1 Publications per researcher



The number of publications per researcher in New Zealand is around double the OECD average, Small Advanced Economies (except Switzerland) and Australia, indicating New Zealand researchers are relatively productive by international standards.

A substantial fraction of publications involve international collaboration. In Figure 1, any publication which includes at least one New Zealand author is assigned to New Zealand. A fairer reflection of each country's contribution may be calculated by 'fractionally assigning' each publication among countries according to how many authors contributed.

When publications per researcher is calculated with 'fractional assignment' to countries, New Zealand still outperforms the Small Advanced Economies (except Switzerland), Australia and the OECD, although its lead is reduced somewhat – from double to around 1.4 times the OECD average*.

† The 2016 edition reported on 'Scholarly output', which is replaced by 'Publications per researcher' in this report. Updated data for the scholarly output indicator is given in the 'Supporting Data Tables' file.

* See Supporting Data Tables for data on fractionally-assigned publications per researcher and per dollar.

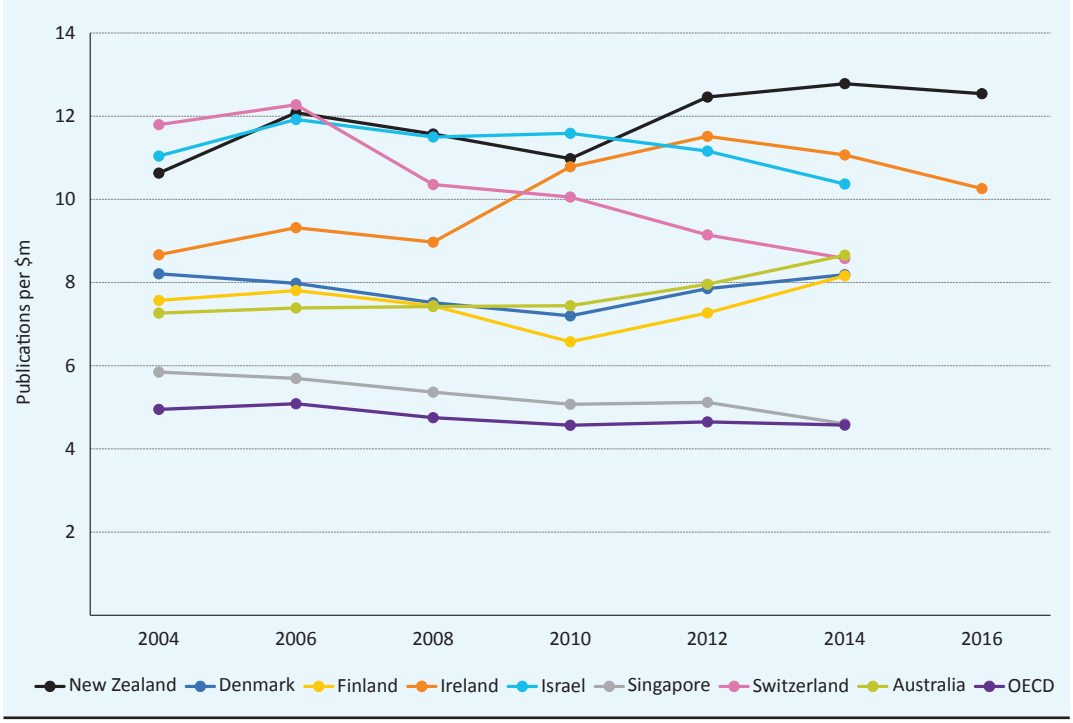
RESEARCH PUBLICATIONS PER MILLION DOLLARS OF RESEARCH EXPENDITURE

The total number of publications per million dollars of research funding is another indicator of the productivity of the science system.

New Zealand does well on publications per dollar of research funding – around 2.7 times the OECD average and top among the Small Advanced Economies. The slight decline since 2014 is mainly due to growth in research expenditure, accompanied by a very small decrease in research publications. Given the lag between research activity and publications, we would expect research output to catch-up with the expenditure growth in future years.

Since New Zealand's publications per dollar are around 2.7 times the OECD average, but publications per researcher are only around double the OECD, we can infer that part of New Zealand's higher output per dollar is due to relatively lower costs per researcher.

Figure 2 Publications per million dollars research expenditure (excluding business expenditure; 2010 PPP USD)



SHARE OF TOP PERCENTILE RESEARCH

This section shows the share of New Zealand's publications in the most highly-cited academic outputs (in the same field) worldwide. Citations are widely recognised as a useful indicator of the academic influence and quality of research, but there are some caveats to their use, including:

- It takes time for a publication to accrue citations so measures may change over time;
- In some cases research may be highly-cited because it is of low-quality – i.e. has a flawed research methodology;
- Research may be relevant to only a very narrow field or impact area, but that does not necessarily mean it is of lower-quality.

Figure 3 Proportion of publications in top ten per cent most-cited worldwide

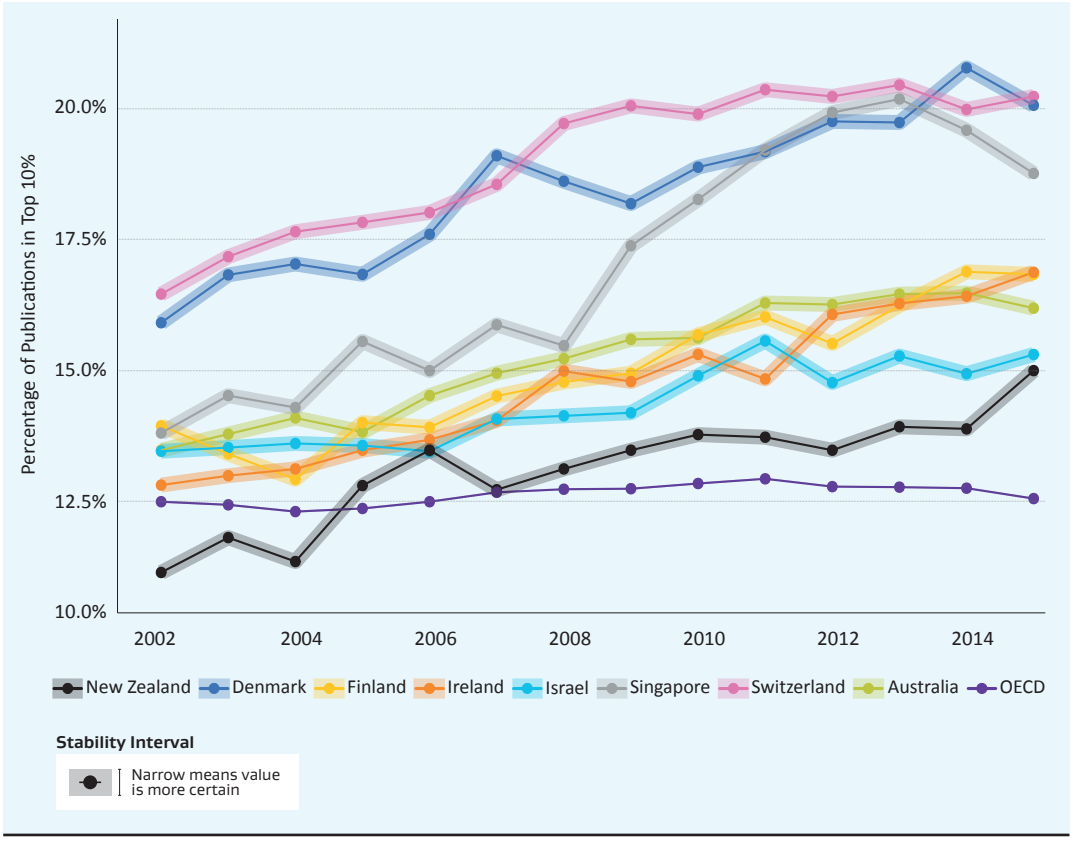


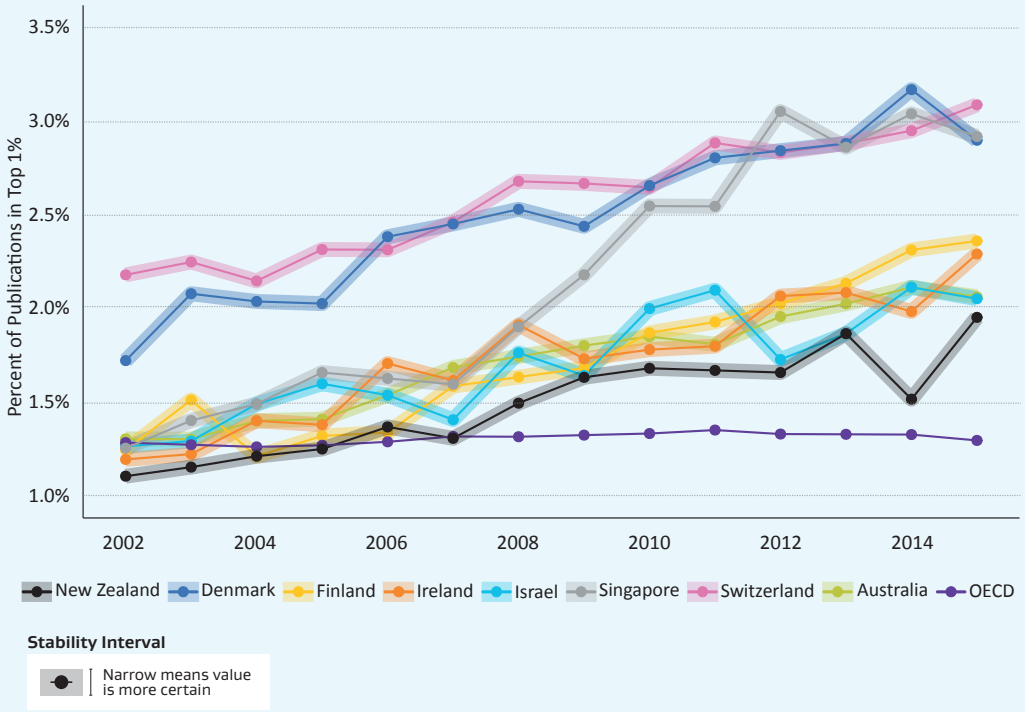
Figure 3 shows that, of the total publications with New Zealand authors in 2015, 15 per cent are currently in the top 10 per cent by citations worldwide. If citations were equally distributed across publications, our share would be 10 per cent. New Zealand remains consistently ahead of the OECD average on this measure, fairly close to Israel, but ranks lower than other Small Advanced Economies and Australia.

Stability intervals

We have introduced stability intervals for the top ten and one per cent measures in this report. Citation measures for a given country or country-field combination can fluctuate significantly from year to year. Stability intervals quantify the underlying variability in the data, which gives us a better sense of whether year-on-year changes in the value of an indicator are meaningful*.

The stability intervals in Figure 3 suggest that the gradual increase in New Zealand's fraction of top-decile publications over the last ten years probably reflect a meaningful change in quality. New Zealand's performance is meaningfully better than that of the OECD since 2007, but meaningfully worse than the Small Advanced Economies and Australia (except Israel in 2015).

Figure 4 Proportion of publications in top one per cent most-cited worldwide



Similar results are seen for New Zealand's production of extremely influential publications (top one per cent). Two per cent of New Zealand's 2015 publications currently appear in the top one per cent most-cited publications worldwide. This is above the OECD average but behind other Small Advanced Economies.

Once stability intervals are taken into account, New Zealand's performance is not meaningfully different from Israel and Australia on this measure in 2015, though still well-behind Switzerland, Denmark and Singapore.

* Stability intervals are calculated in a similar fashion to statistical confidence intervals. They do not strictly have the same interpretation as an estimate of sampling error, because the data are complete rather than a sample.

Focus Box

New Zealand's Research Specialisation

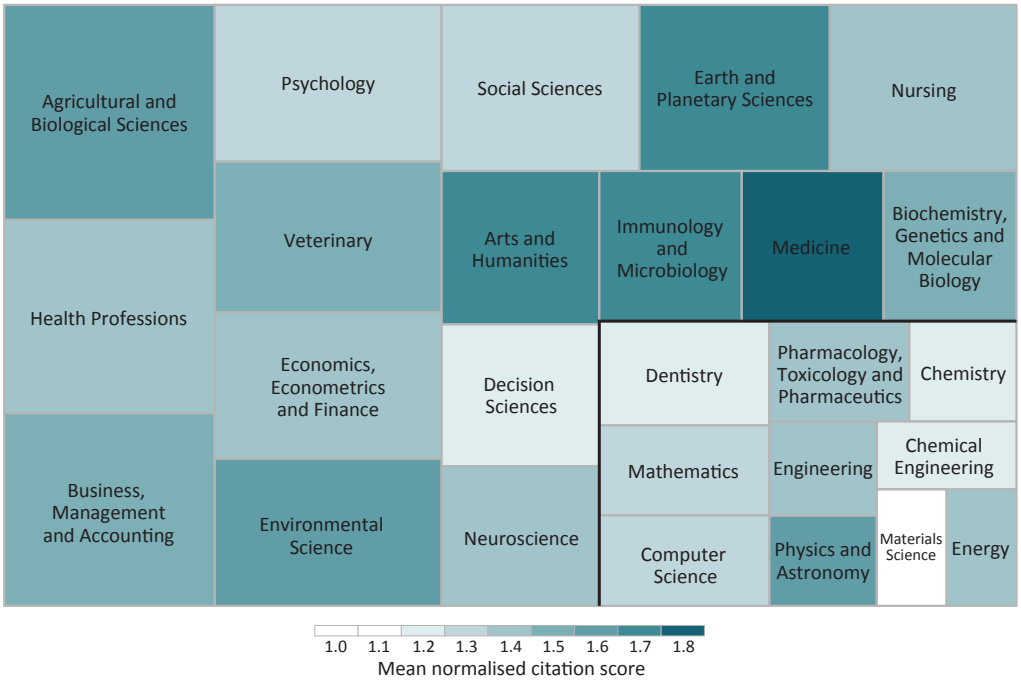
ACTIVITY INDEX

The Activity Index*,1 shows a country's degree of specialisation in different research fields. It shows what proportion of a country's research publications are in a given field, relative to the proportion of total global output in that field. It is similar to the revealed comparative advantage measure used by economists to explore a nation's industrial specialisation based on export mix.

We have presented three different citation-based research quality measures alongside the activity index in the figures in this section. The distribution of citations to publications is highly-skewed – in a given field there are usually a few very highly-cited publications and a 'long tail' of less or uncited publications. The three citation-based measures used here tell us about the average (Figure 5), top end (Figure 6), and bottom end (Figure 7) of research performance.

In Figure 5 the size of each box is the Activity Index for each research field in New Zealand. The shading indicates the average citation impact of New Zealand publications in that field (mean normalised citation score†).

Figure 5 New Zealand's total production share relative to the world in research volume (size of box) and average citation impact (shading) 2011–2015



* The activity index is the relative degree of specialisation in research field (F) by a nation (N), given by:

$$AI(N,F) = \frac{(\text{Proportion of country N publications which are in field F})}{(\text{Proportion of world publications which are in field F})}$$

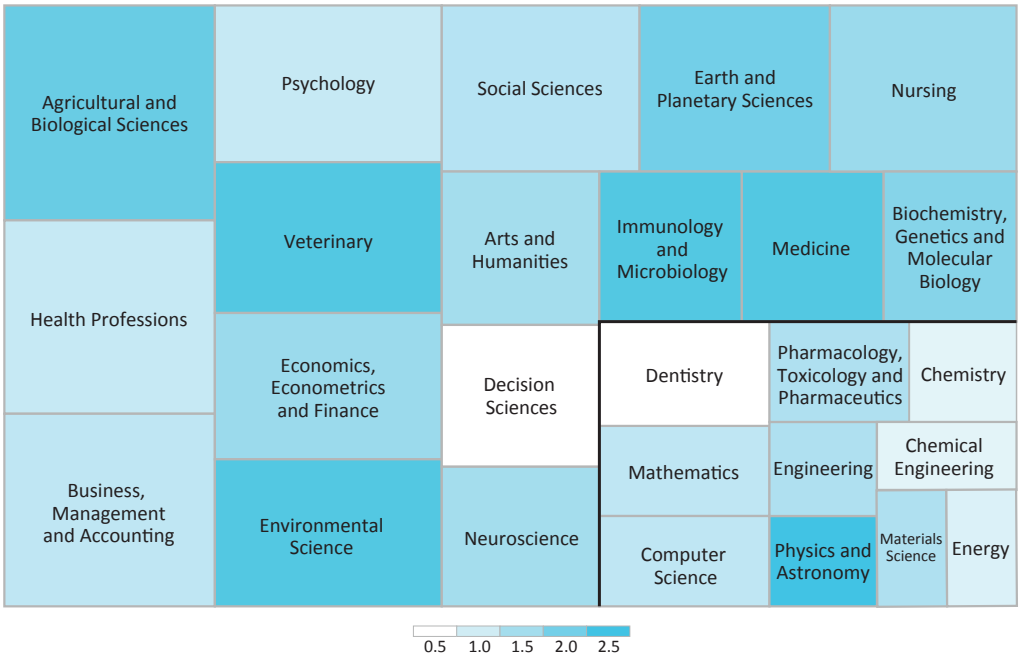
† The mean normalised citation score (mncs) presents the average citations per publication, normalised to average citations received by all publications in the same year, type and field.

New Zealand produces more publications than the world average in the fields above and to the left of the black line.

The highest average citation impact is achieved in Medicine, Earth and Planetary Sciences, Arts and Humanities, and Immunology and Microbiology.

Figure 6 and Figure 7 show the same data on relative publication volume, but the shading shows different measures of research quality. Figure 6 shading indicates the proportion of publications in the top percentile most-cited for their field. This is an indicator of really excellent research and shows a similar distribution to the average citations in Figure 5.

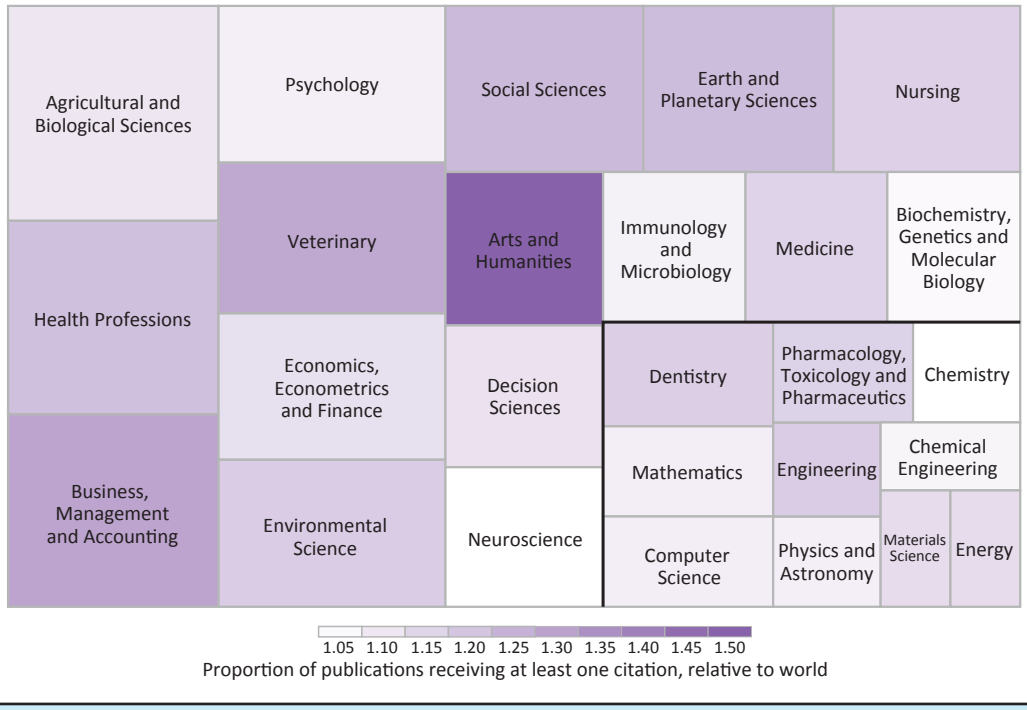
Figure 6 New Zealand's total production share relative to the world in research volume (size of box) and publications in top percentile most-cited for the field (shading) 2011–2015

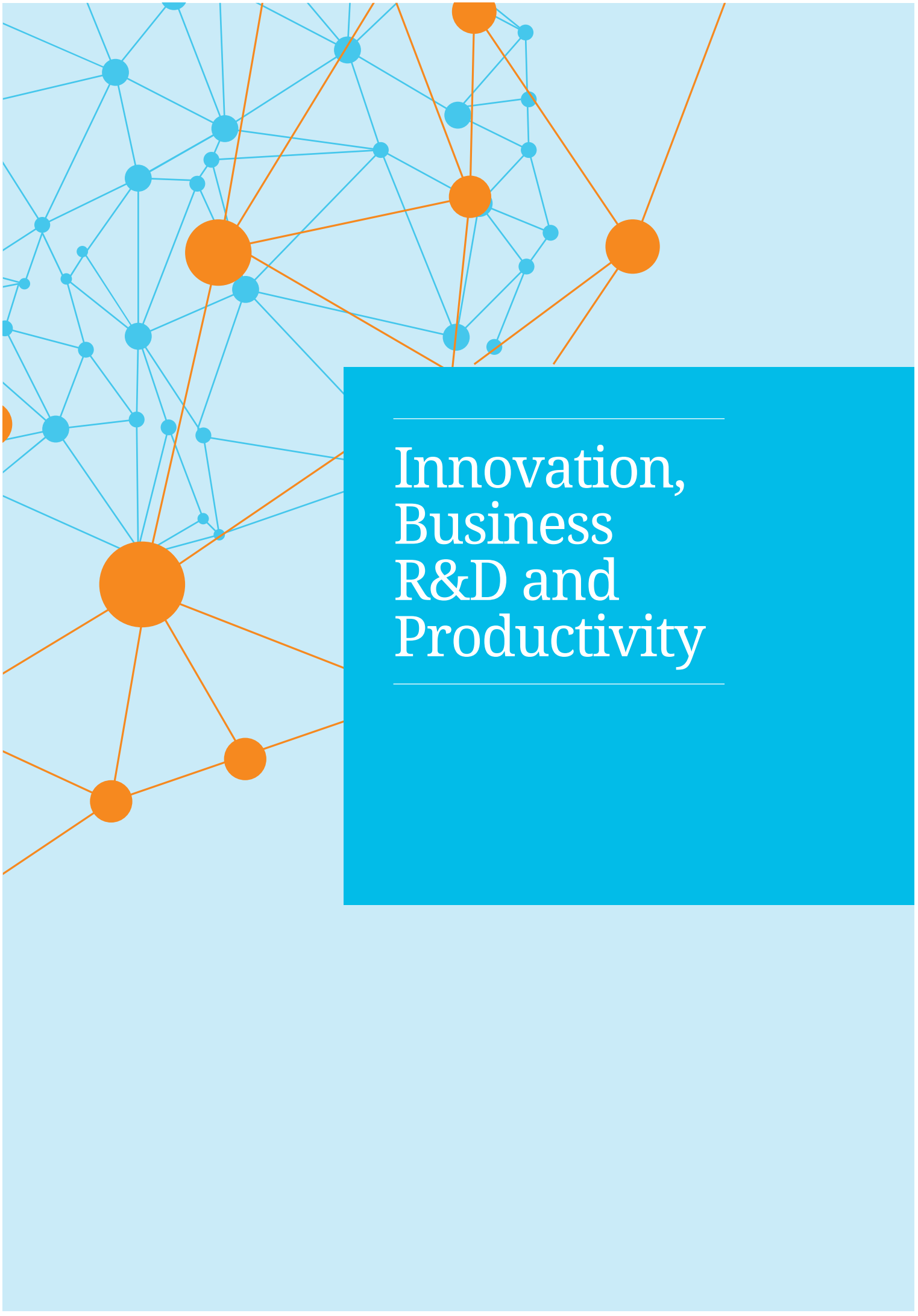


Focus Box

Figure 7 shading indicates the fraction of publications which have received at least one citation (normalised to the fraction of publications which are cited worldwide for that field). This is an indicator of the fraction of research which is having any influence at all on its field. New Zealand performs better than the world average in all fields on this measure. The notable high-performing field is Arts and Humanities, in which 66 per cent, of New Zealand publications have at least one citation, compared with 45 per cent for the world.

Figure 7 New Zealand's total production share relative to the world in research volume (size of box) and fraction which have of received at least one citation (field-weighted, shading) 2011–2015. Fields above and to the left of the black line are those where New Zealand publishes more than the global average





Innovation, Business R&D and Productivity

Innovation, Business R&D and Productivity

Innovation, business R&D and productivity are closely linked, as briefly described below. This section presents data across these areas, including a focus on New Zealand's start-up ecosystem – a key source of disruptive innovation.

INNOVATION

Innovation in the private sector is defined as the introduction of new or significantly improved goods, services, processes, or marketing methods*. Research and Development is one way to innovate, by providing new knowledge and enabling new technological capabilities and practice.

Innovation in the health or education sectors or in policy may lead to better ways of delivering government services and better outcomes for individuals, society and the environment. Indicators of public-sector innovation are not well-developed so this section focuses on private sector innovation and productivity outcomes.

PRODUCTIVITY

Innovation contributes to productivity by enabling firms to produce more value for a given input – increasing revenues, reducing costs and maintaining competitiveness. Innovation is widely accepted as a key driver of economic productivity, alongside other factors including skills, investment and a stable regulatory environment.

Higher economic productivity is one way to raise living standards. New Zealand has a long-running productivity shortfall versus the OECD average (see Figure 8). OECD analysis suggests that low-levels of R&D investment are a key driver of New Zealand's productivity shortfall, alongside our small size and distance from international markets[2].

ECONOMIC GEOGRAPHY

As well as its small size and distance from international markets, New Zealand's low population density makes it challenging to achieve benefits from agglomeration[3] for innovation and productivity.

There is also some evidence that weak competitive pressures in New Zealand contribute to lower productivity. The OECD suggests this is linked to economic geography – as a smaller market means fewer competing firms, and distance from other countries creates barriers to entry by foreign providers[4].

* Oslo Manual, OECD

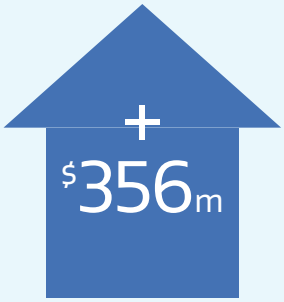
Business R&D expenditure is low...

Business expenditure on R&D as % GDP (latest available data)

New Zealand	0.63%
Denmark	1.89%
Finland	1.93%
Ireland	1.09%
Israel	3.63%
Singapore	1.34%
Switzerland	2.43%
Australia	1.19%

...but growing strongly

Business R&D increased by $356m (29%) from 2014-16



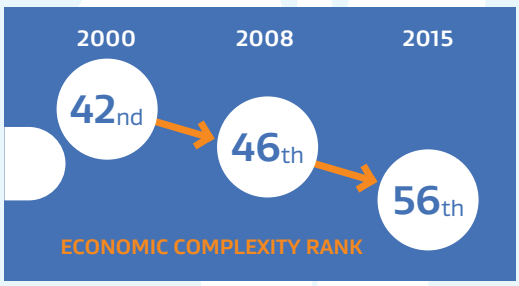
Innovation rates are low

Proportion of firms reporting innovation (latest available data)

New Zealand	49%
Denmark	49%
Finland	55%
Ireland	61%
Switzerland	75%
Australia	66%

Our economic sophistication is falling behind the global frontier

New Zealand's world economic complexity rank



Top R&D spenders

Sectors which perform the most R&D

Manufacturing

42%

Computer services

27%

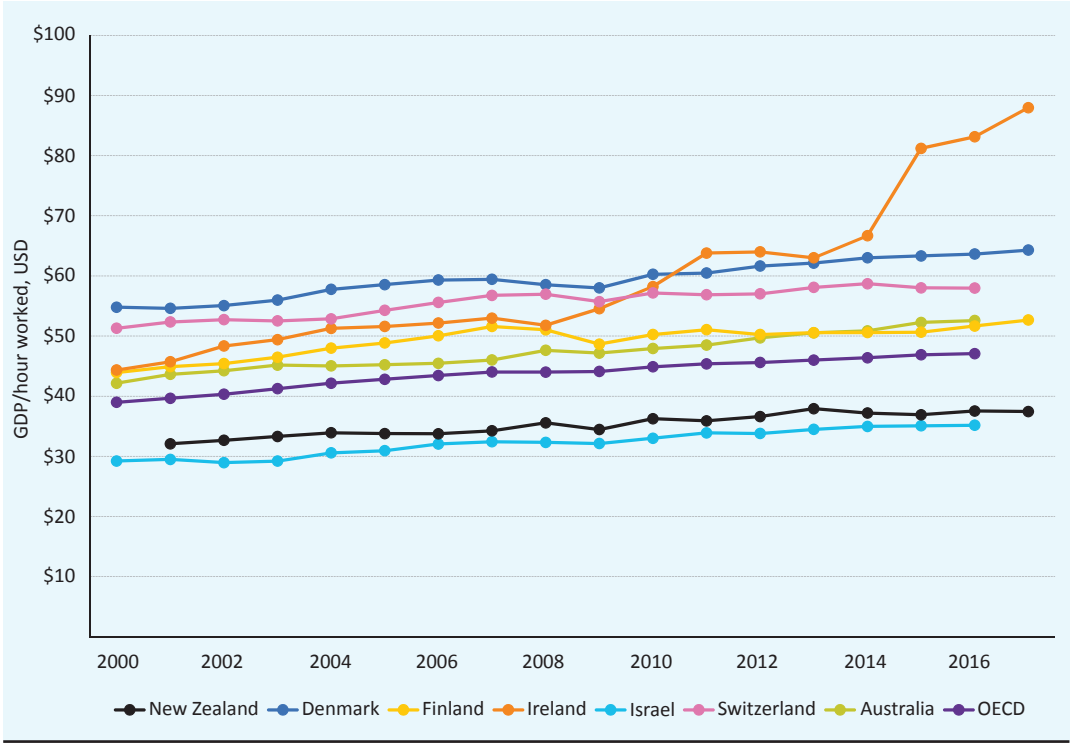
PRODUCTIVITY DATA

Gross Domestic Product per hour worked

Productivity can be measured in several ways, but has a general definition of the ratio of output to input. Gross Domestic Product per hour worked is one measure of productivity. Figure 8 shows New Zealand's poor performance on this metric versus the OECD, other Small Advanced Economies and Australia. New Zealand is currently ranked 22nd out of the 30 OECD countries in the productivity league table[5], and an hour worked in New Zealand typically generates 36 per cent less output than an hour worked in Australia.

This is reflected in lower average wages – an important aspect of job quality. In New Zealand people earn USD 38,346 per year on average, slightly less than the OECD average of USD 42,162[6].

Figure 8 Comparison of New Zealand's GDP per hour worked with Small Advanced Economies and Australia



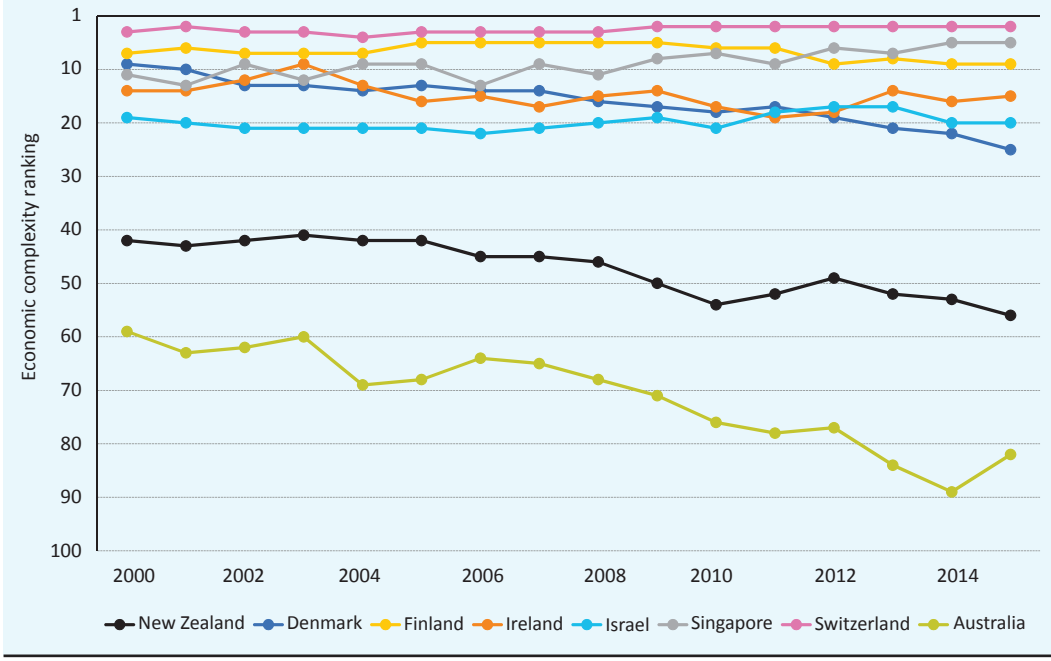
The sudden spike in Ireland's apparent productivity in 2015 is not due to a radical change in the way industries or firms function, but rather reflects financial restructuring of multinational companies to take advantage of tax rules[7].

Economic complexity

Economic complexity is a measure of the diversity and complexity of a country's exports. This measure shows New Zealand's rank in the world compared to other Small Advanced Economies based on the complexity of the products we export. More complex economies produce a greater range of more complex products, which require higher technological capabilities and skills.

More economically complex countries have been shown to be more economically developed or on the cusp of rapid economic growth.

Figure 9 Economic complexity ranking



New Zealand performs poorly compared with other Small Advanced Economies, and ranks 56th overall in the economic complexity world ranking. Our place in this ranking has deteriorated over time; however, we rank consistently higher than Australia in this measure. This may reflect the importance of minerals and fuels in Australia's exports.

A shortcoming of this measure is that it is likely to understate complexity in products which is not directly embodied in the products themselves. For instance, New Zealand's comparative advantage by and large is in primary products, which are simple in nature. The differential sophistication of primary production and post-harvest processes between countries would not be captured in economic complexity measures (for example, expertise in animal and plant breeding or automation of food and beverage processing).

The economic complexity measure also excludes services, so would not capture New Zealand's growth in areas such as computer services.

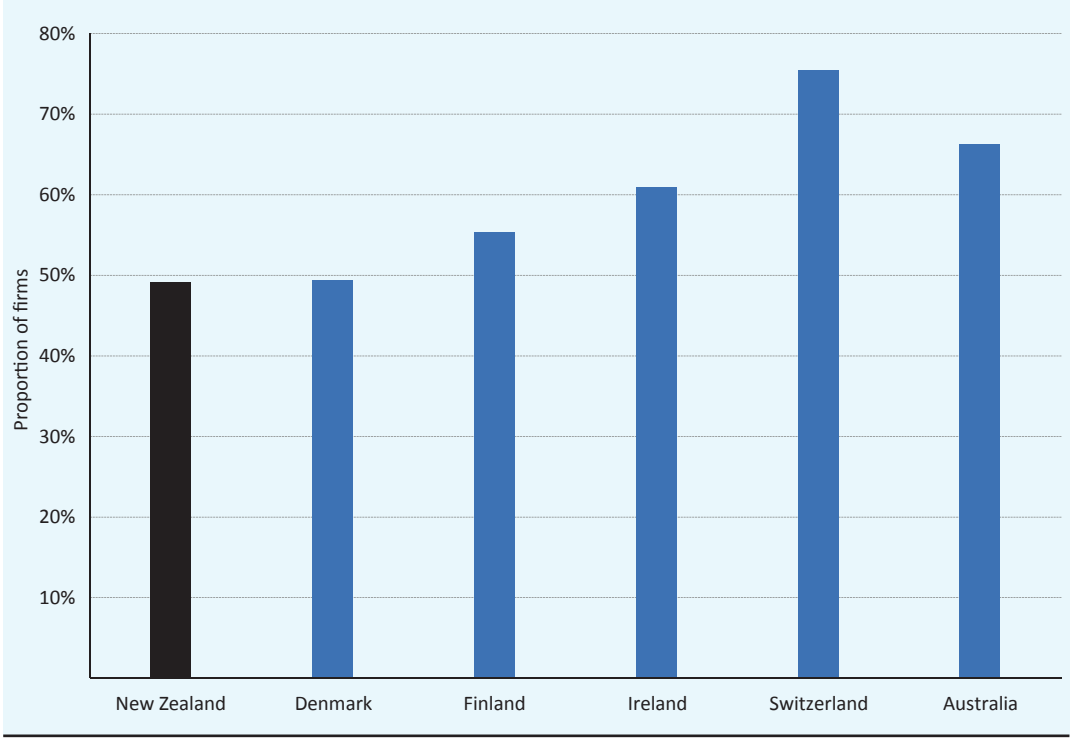
INNOVATION RATE

There are a number of issues with comparing data on innovation rates internationally, including differences in survey wording and firm population, such as the firm sizes covered. With these caveats, the available data suggest New Zealand innovation rates are around the average for the OECD, but mostly lower than Small Advanced Economy comparators.

Rates of innovation reported by firms

Figure 10 shows an international comparison of self-reported business innovation rates based on 2012-14 data. More recent data show little change in New Zealand's performance (47 per cent of firms reported innovation in the 2017 Business Operations Survey, compared with 49 per cent for 2012-14).

Figure 10 Proportion of firms that innovate, 2012-14



Split of new-to-market versus new-to-firm innovation

Figure 11 shows the split of product innovation reported by New Zealand firms between 'new to market' and 'new to firm' innovations.

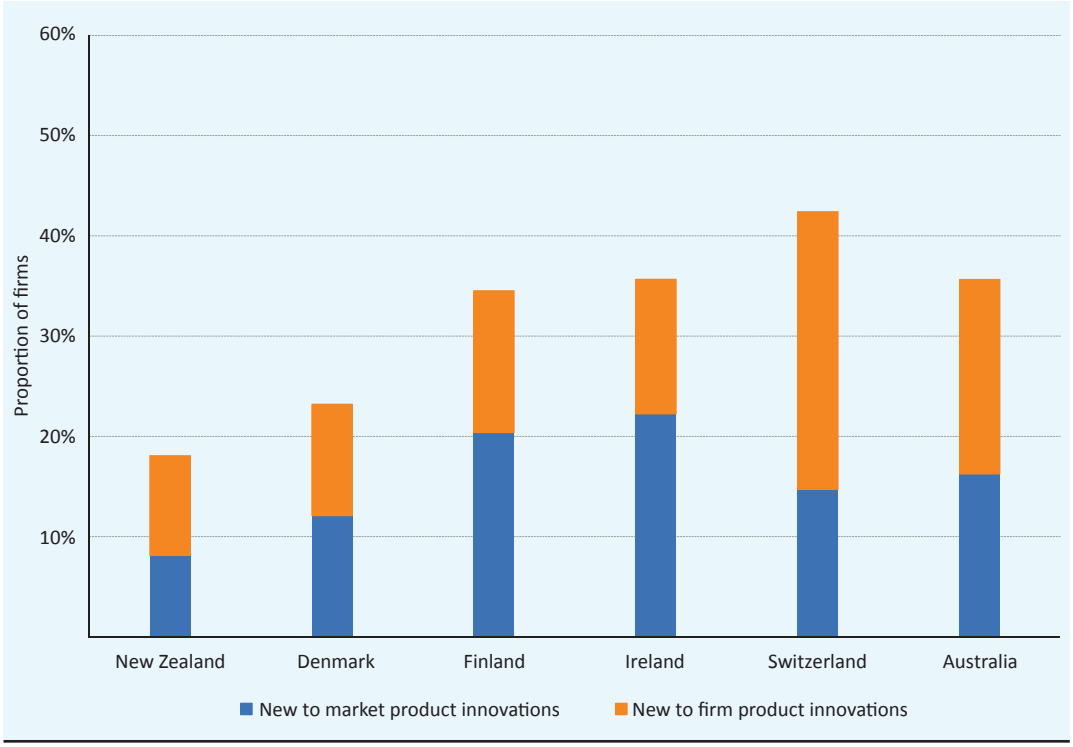
- New to market innovation is the first introduction of a product in a domestic market. These could be New Zealand inventions, or copied from overseas.
- New to firm innovation refers to firms copying products already present in their market.

These processes of local invention, diffusion of ideas within the New Zealand market, and adopting overseas innovation, are all important for industry sectors to keep pace with the technological frontier and remain competitive. Distance from international markets may make it more challenging for New Zealand firms to adopt the latest international innovations.

It is not clear that a shortfall in either of these processes is responsible for New Zealand's overall lower innovation rate.

Figure 11 shows that product innovations reported by New Zealand firms are roughly equally split between 'new to market' and 'new to firm'. The ratio between these classes varies in the other countries shown, so it is not clear that a shortfall in either of these processes is responsible for New Zealand's overall lower innovation rate.

Figure 11 Product innovations reported by firms



Focus Box

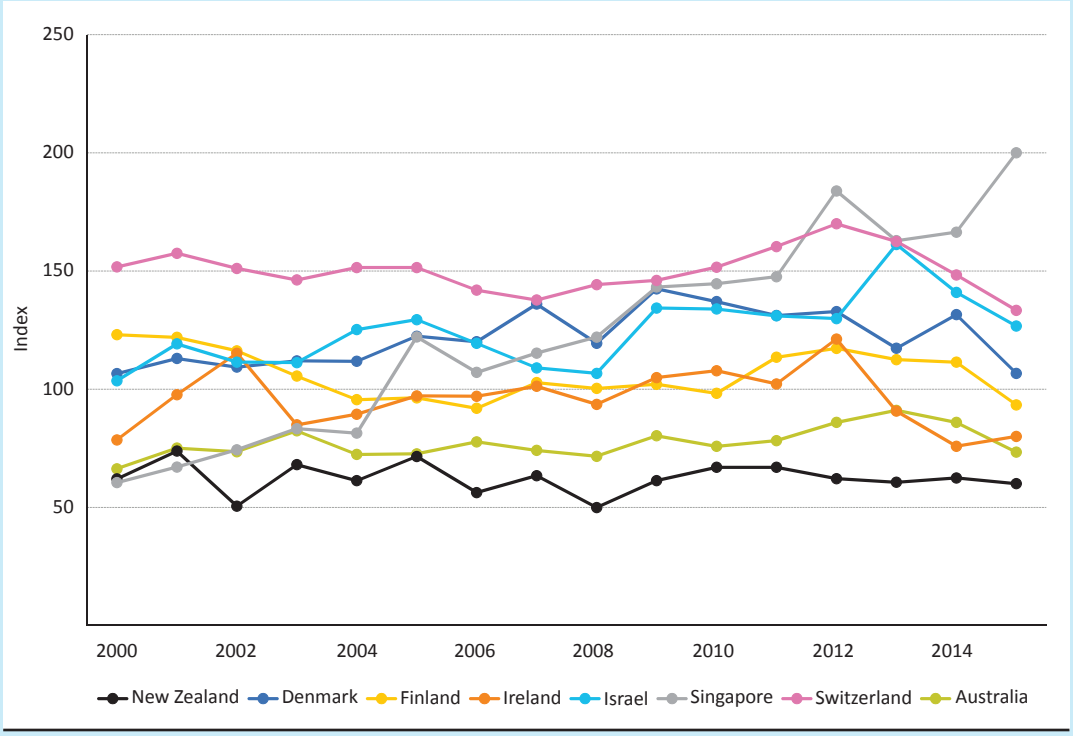
Patents and publications

Patents are one of the more easily measurable outputs of research. Citations from patents to academic publications are an indication that the research has contributed to an invention with potential commercial value. This can therefore be considered as a further step along the pathway to impact than an academic citation.

Citation of New Zealand research in international patents

A relatively small fraction of New Zealand research is cited in international patents. This suggests our research is relatively less influential in terms of leading to globally-relevant inventions.

Figure 12 Research cited by patents (normalised to OECD average for year)



There are a number of caveats with this measure, including:

- If research findings are close enough to the invention to constitute 'prior art', then a researcher seeking to protect this intellectual property will normally patent before publishing. Therefore this measure may not capture the most critical research contribution to an invention.
- Patents are only one way in which research findings lead to impacts. They are less relevant in some economic sectors (such as software development) and in environmental and social areas.

Focus Box

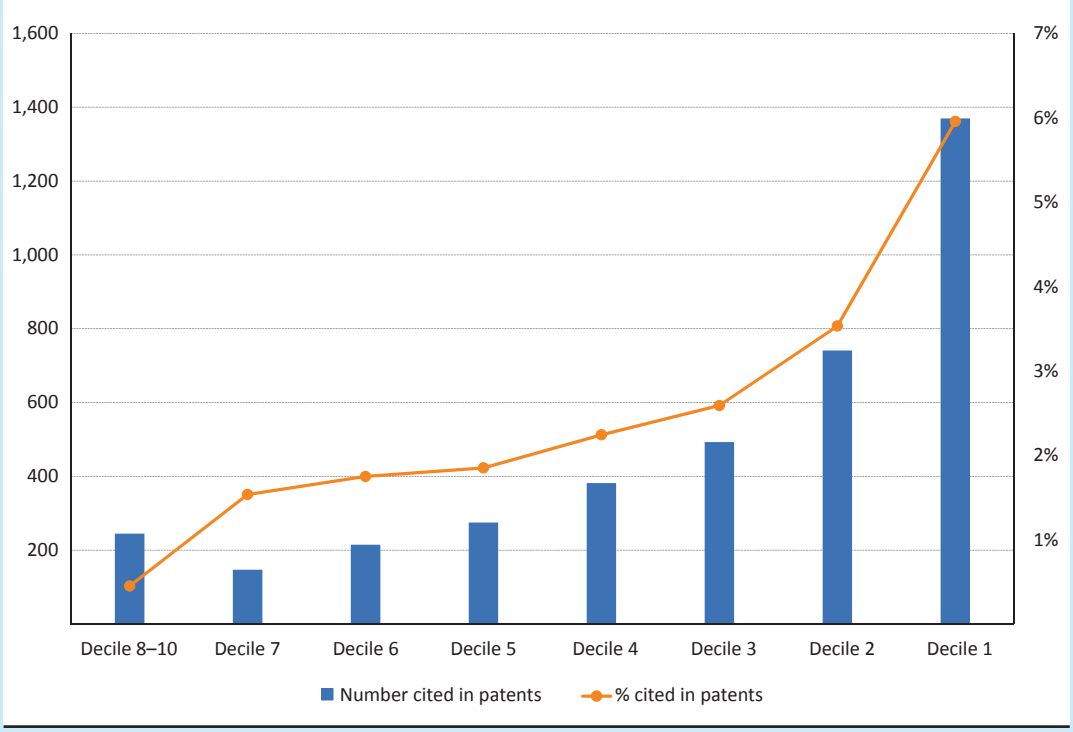
Relationship of academic citations to patent citations

Citations of research in other academic papers indicate scholarly influence (and are used as a proxy for research quality), while citations of research in patents indicate commercial potential.

We used linked publication-patent data to analyse the relationship between the academic citations and patent citations to research.

The results for New Zealand are plotted in Figure 13, which shows the number of patent citations to publications in each academic citation decile. This suggests a strong correlation between scholarly influence and commercial potential.

Figure 13 New Zealand publications cited in patents, by academic citation decile



This is an important step towards demonstrating a link between scholarly influence and/or research quality and potential impact.

There are a number of important caveats to this analysis:

- Many patents cite a large number of references, so it is unclear how much influence the cited New Zealand research can actually claim in the invention;
- Some patent citations may be to research which is only peripherally relevant to the invention, and in fact research which actually contains the essence of the invention in the patent would count as prior art, and prevent a patent from being granted;
- We don't know what commercial benefit New Zealand may have gained from these inventions.

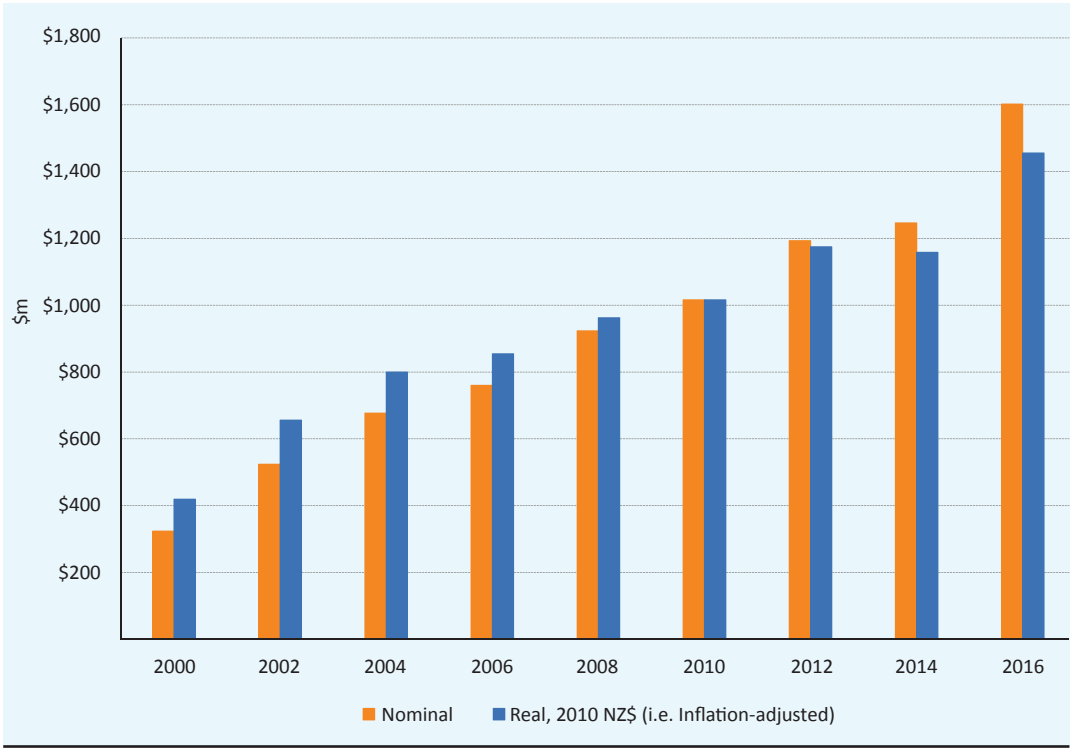
BUSINESS EXPENDITURE ON R&D

Business expenditure on R&D (BERD) is often used as an indicator of the amount of innovative activity within businesses. Business R&D generates the knowledge base needed to develop new processes and products which can raise a nation's long-term productivity and international competitiveness.

As a measure of innovation, R&D has an advantage over self-reported innovation rates, because dollar expenditure on research and development activity is relatively objective. On the other hand, R&D is only one input to innovation, so any particular R&D programme may not successfully result in innovation, and this measure will also miss other types of innovation, such as marketing.

Between 2014 and 2016, business expenditure on R&D grew substantially by NZ$356m (29 per cent), increasing total BERD to $1,602m from $1,246m in 2014. This is an increase from 0.54 per cent to 0.63 per cent GDP.

Figure 14 Business expenditure on R&D (Nominal and Real)



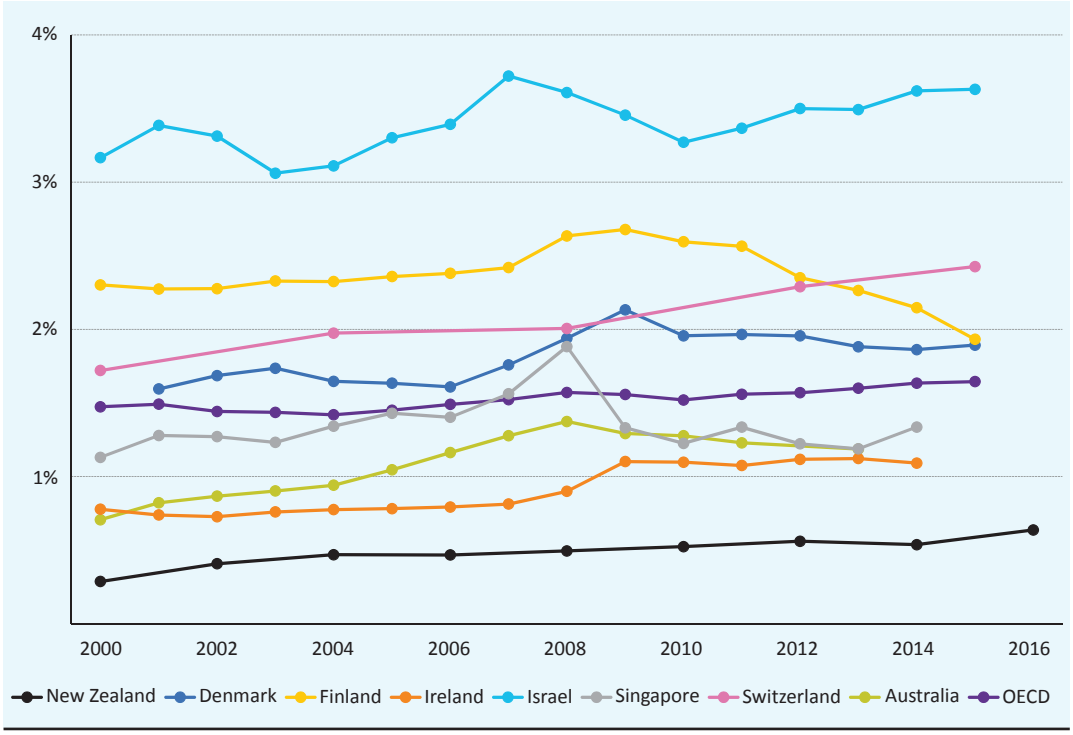
It is possible that this dramatic increase in BERD reflects additional incentives for business R&D following the creation of Callaghan Innovation in 2014. The most recent available data (not shown in Figure 14 & Figure 15) suggest continued strong growth in BERD to $1,840m* in 2017.

* This figure is estimated based on the year-on-year R&D growth reported by firms in the Business Operations Survey. The Business Operations Survey sampling methodology means it gives less reliable results for this figure than the two-yearly R&D survey.

International comparison of business expenditure on R&D

In spite of BERD growing more strongly than GDP, the international comparison hasn't changed dramatically since the last System Performance Report – New Zealand continues to have the lowest BERD:GDP ratio among its peer group (Figure 15).

Figure 15 Business expenditure on R&D as a percentage of GDP



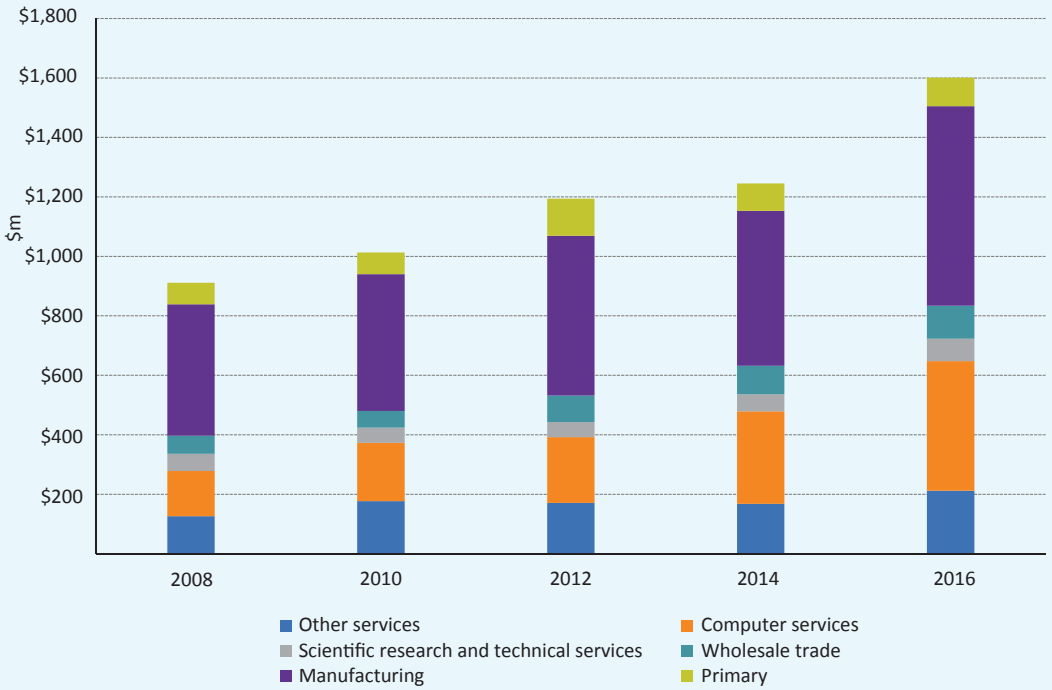
Over the years, various commentators such as the Productivity Commission, MBIE, the Treasury and the OECD have put forward factors responsible for New Zealand's low BERD, including[9, 10]:

1) Industry structure, i.e. R&D-intensive industries make up a smaller share of the economy;
2) Low R&D intensity across all industries;
3) Low levels of competition;
4) A small domestic market and geographical isolation, which may reduce returns to innovation;
5) Lack of connectivity across research and industry networks to provide necessary scientific or technical input; and
6) Lower relevance and depth of research capability in research organisations manifested as a lack of available researchers to develop technologies needed by firms.

R&D expenditure by industry

This section shows the contributions of different economic sectors to total BERD.

Figure 16 Share of R&D expenditure by Industry



The manufacturing and the computer services sector dominate BERD and are driving BERD growth, contributing $275m of the $356m increase in spending between 2014 and 2016.

The Manufacturing sector is the largest sector in terms of business expenditure on R&D at $671m (42 per cent), including $117m from Food, Beverage and Tobacco manufacturing in 2016. Manufacturing BERD has grown by 52 per cent since 2008.

The Computer Services sector follows next with $436m (27 per cent) invested in 2016, an increase of $125m (40 per cent) over 2014. It is also the fastest growing sector since 2008, with an increase of 186 per cent (CAGR* of 14.1 per cent).

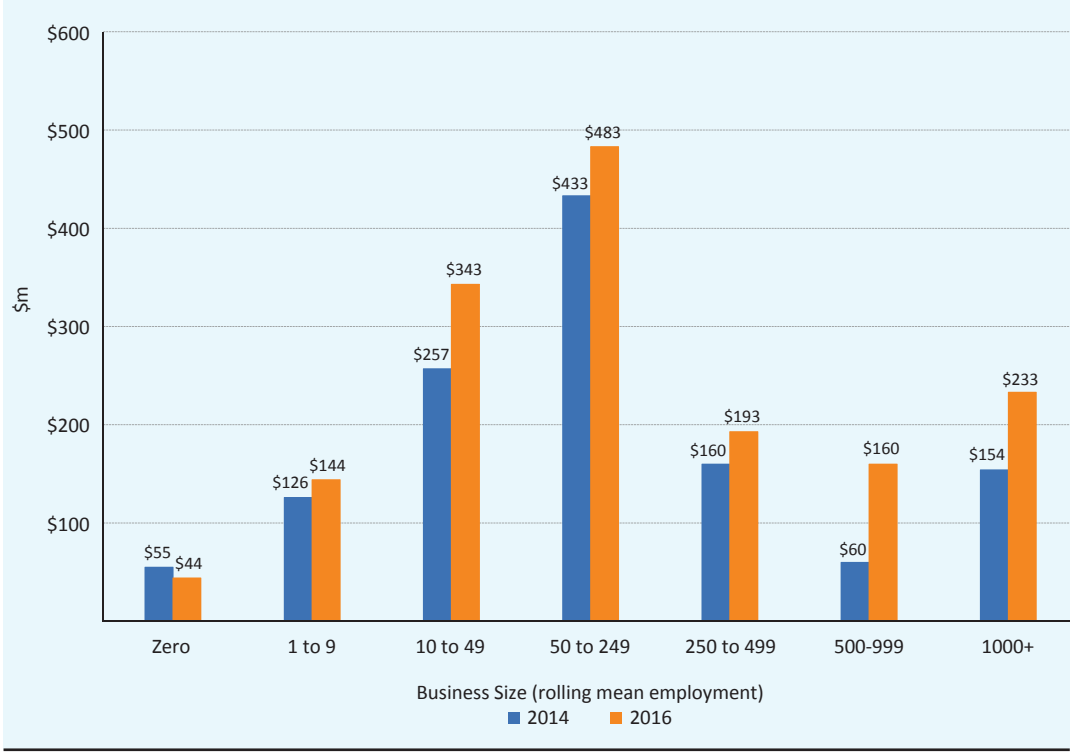
Strong growth in Computer Services BERD is consistent with it being a frontrunner for innovative start-up activities in New Zealand. It received the largest share of known early-stage start-up investment (42 per cent of total amount invested in start-ups by angel companies) between 2006 and 2016[11]. Starts-ups are further discussed on pages 31-34.

* Compound annual growth rate

Distribution of BERD by company size

The spread of total R&D expenditure across firms of different sizes reveals a rather uneven distribution.

Figure 17 Total business expenditure on R&D by company size (rolling mean employee count)



Firms employing 50-249 employees contributed the most towards BERD in 2016 ($483m) followed by firms with 10-49 workers ($343m). High growth is mainly due to growth in the average spend per firm (see Figure 19 for average spend per firm).

Firms with 500 or more employees contributed 50 per cent of the 2014-16 BERD growth. The largest growth since 2014 occurred in the 500-999 employee group, which increased total R&D spend from $60m to $160m.

The proportion of businesses performing R&D has remained stable from 2014-16, except in the 500-999 employee category, where the rate has fallen from 16.4 per cent to 12.3 per cent. This decrease has been outweighed by increased average spend per firm in that category (Figures 18 and 19).

Figure 18 Proportion of businesses doing R&D

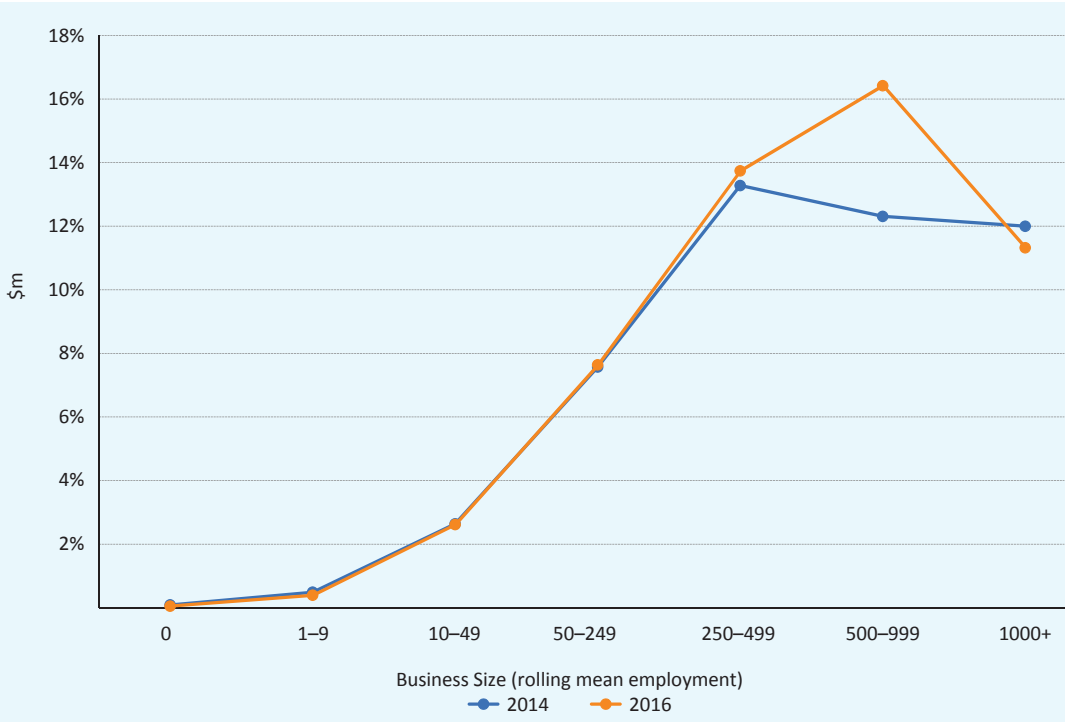
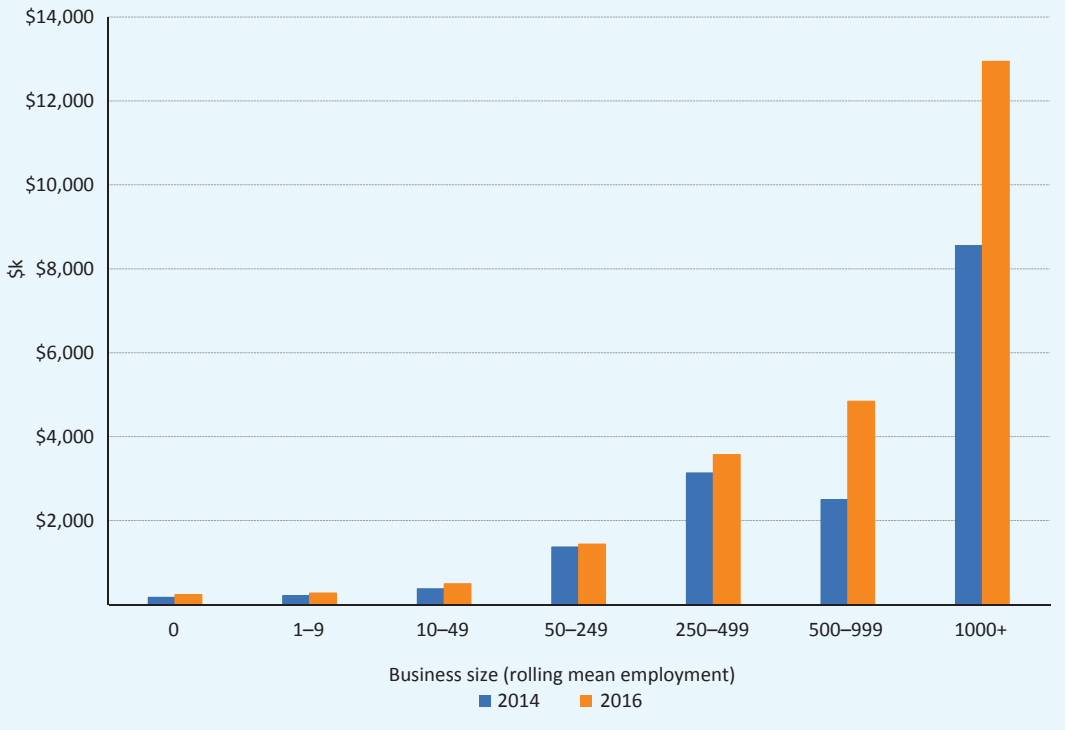


Figure 19 Average expenditure by R&D performers

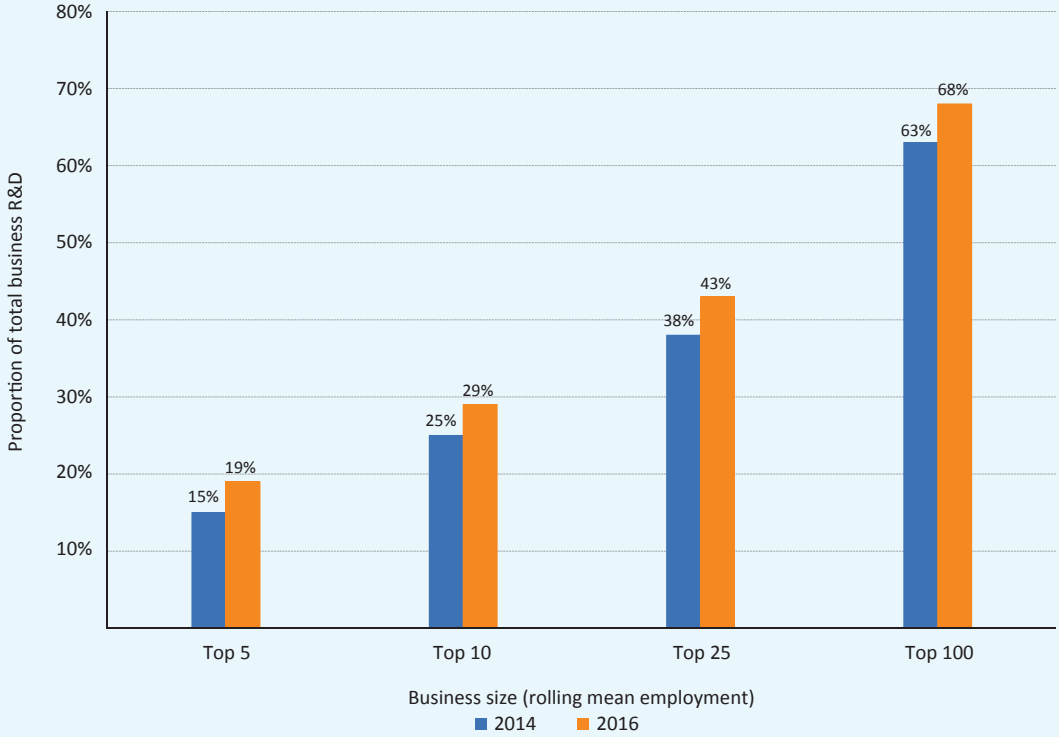


Business expenditure in R&D by top-spenders

Figure 20 shows what proportion the top 5, 10, 25 and 100 R&D spenders contribute to total BERD (firm count).

This reveals a skewed distribution, with a few large spenders contributing a disproportionately large amount of total BERD. This pattern is seen in other countries. For example, of the 4,185 businesses performing R&D, the top 100 businesses (2 per cent of R&D performers) contributed 68 per cent of expenditure in 2016.

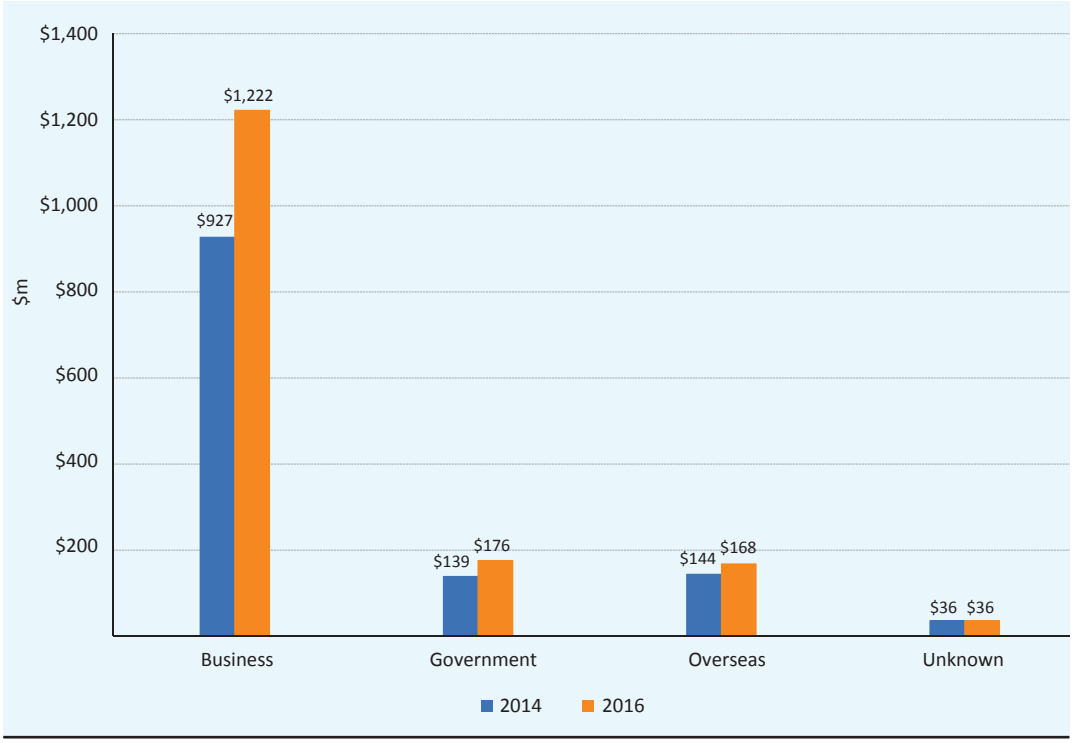
Figure 20 Business expenditure in R&D by top-spenders



Source of funds

Figure 21 shows the sources of funding for R&D which was performed by businesses in 2014 and 2016. This shows that the majority of BERD growth between 2014 and 16 was funded by New Zealand business itself.

Figure 21 How business R&D was funded*



* Funding of 'unknown' portion is confidential due to Statistics NZ data policies

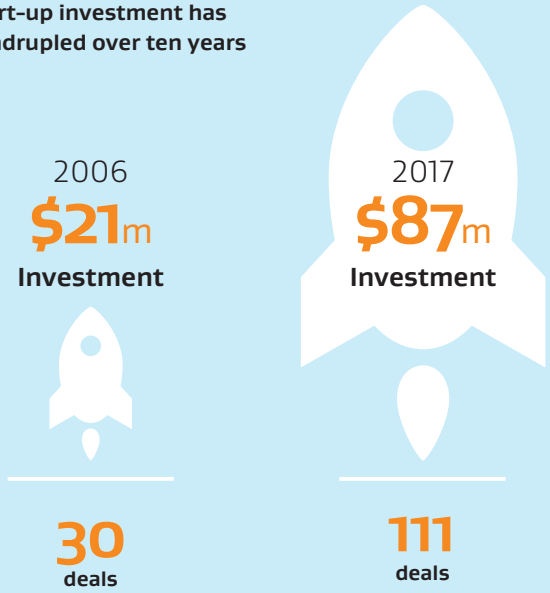
Start-ups

'Start-up' usually refers to a young, small, innovative company, with high-growth ambitions, although there is no formal, agreed definition. They are often associated with software, but are seen in a wide range of sectors, such as health, high-value manufacturing or agritech, and may be based on technology and/or business model innovation.

There is evidence globally that a small number of young and innovative firms generate a disproportionate share of new jobs. These jobs are also more likely to be knowledge-intensive and high-quality.[12]

Start-ups tend to be regionally concentrated, giving rise to the concept of a 'start-up ecosystem', which includes local entrepreneurs, skilled and creative people, investors, research institutions, business schools, incubators and start-ups, and larger firms in related sectors. Some of the most famous start-up ecosystems are Silicon Valley in California, Boston (where Massachusetts Institute of Technology is located) and Berlin, home of WISTA Science Park, numerous creative industries, leading entrepreneurs and start-up firms.

Start-up investment has quadrupled over ten years



INVESTMENTS IN START-UPS

Start-ups have several options for funding.

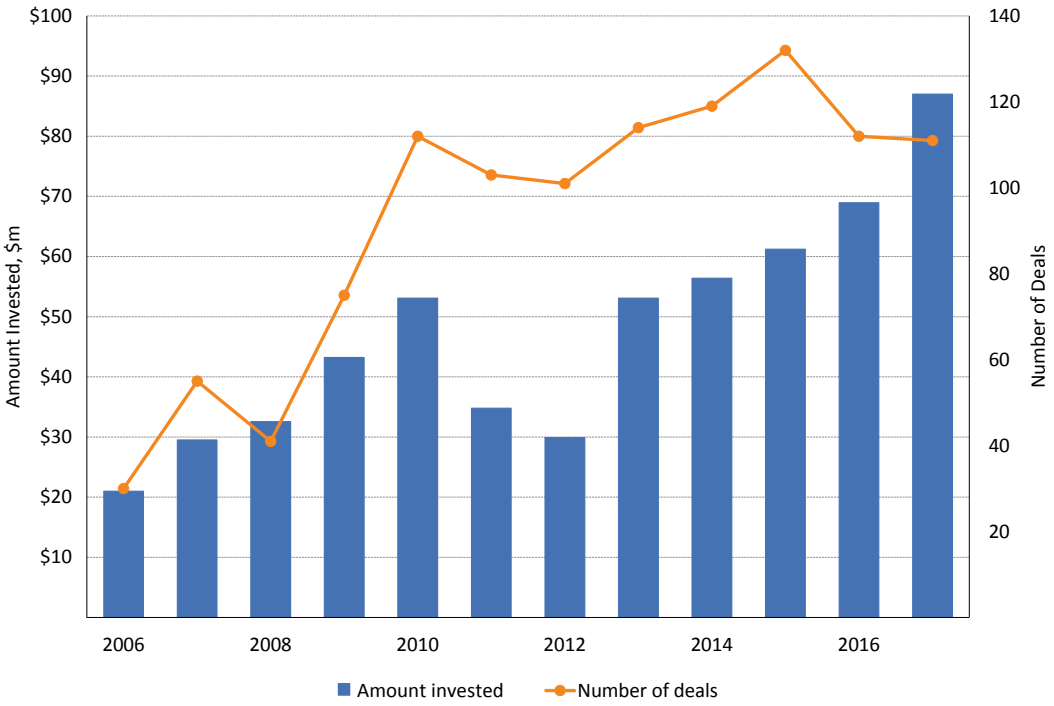
- **Angel investors** are wealthy individuals investing their own funds to help start-up companies begin operations, exchanging seed money for an equity stake in the firm. Angel investors may also collaborate with each other as part of 'angel networks'. In New Zealand, the Seed Co-investment Fund (SCIF) is a $50m fund which directly invests and supports formal 'angel' investment networks through a co-investment partnership model.
- **Venture Capital (VC)** funders are companies which raise capital from others to invest in early-stage firms. This gives VC's access to more funds and a more conservative risk attitude than Angel investors, so they are more likely to provide funding at a later stage. In New Zealand, the Venture Investment Fund (VIF) is a Government owned professional venture capital fund of $195m. VIF co-invests with the private sector into new venture capital funds.
- **Crowdfunding** is a small but increasing source of finance, which allows start-ups to seek funding online from a large number of individual investors.

Because of the private nature of start-up funding deals, it is hard to gather complete data on the activity of this area. We have drawn data from the Young Company Finance Index Report, the Start-up Genome Global Start-up Ecosystem Report, the OECD and the PwC start-up investment magazine. These are not complete data sets. For example, the Young Company Finance Index only includes angel investment by formal angel investor groups – this is a subset of the total. The Start-up Genome report only includes data on 'Tech' start-ups.

Focus Box

Angel investment figures from the Young Company Finance report indicate substantial growth in the early-stage New Zealand start-up ecosystem over the last ten years, from $21m in 2006 to $87m in 2017 – a CAGR of 14 per cent. These figures are incomplete because they only include angel investment by formal angel investor groups.

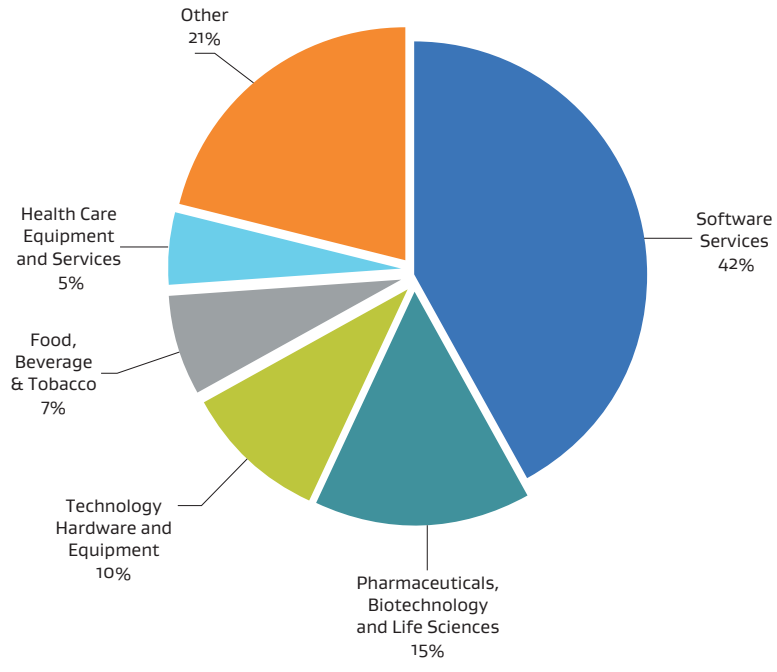
Figure 22 Early stage capital investments and deals



Angel investments by sector

Figure 23 shows the proportion of angel investments across sectors between 2006 and 2016.

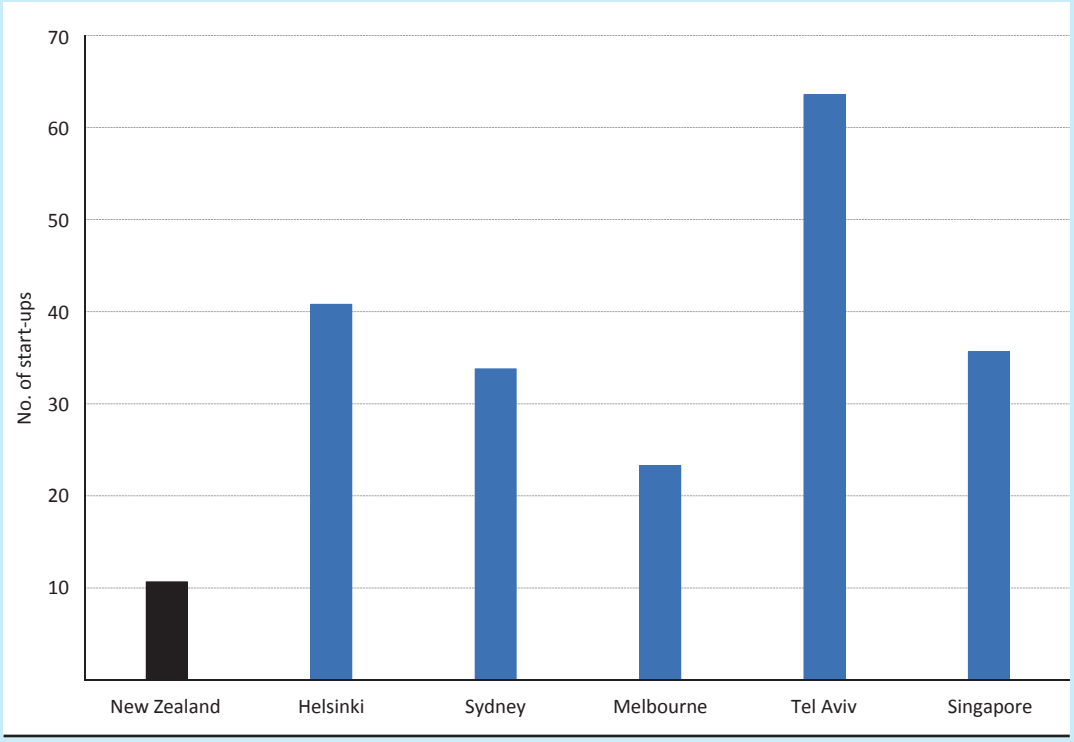
Figure 23 Angel investment across sectors 2006–2016



INTERNATIONAL COMPARISON OF TECH START-UPS

Innovative start-up activity in New Zealand is gaining momentum but currently lags behind other Small Advanced Economies and Australia. The Start-up Genome's Ecosystem Report describes New Zealand as being in the "Activation phase"* indicating relative immaturity when compared globally. Start-up Genome estimates that New Zealand is home to 400-600 start-ups in the software based tech sector.

Figure 24 Number of 'tech' starts-ups per hundred thousand people



The Start-up Genome report compares start-up ecosystems across global cities, but looks at New Zealand as a whole. This means the data are not strictly comparable, but still provides useful insight.

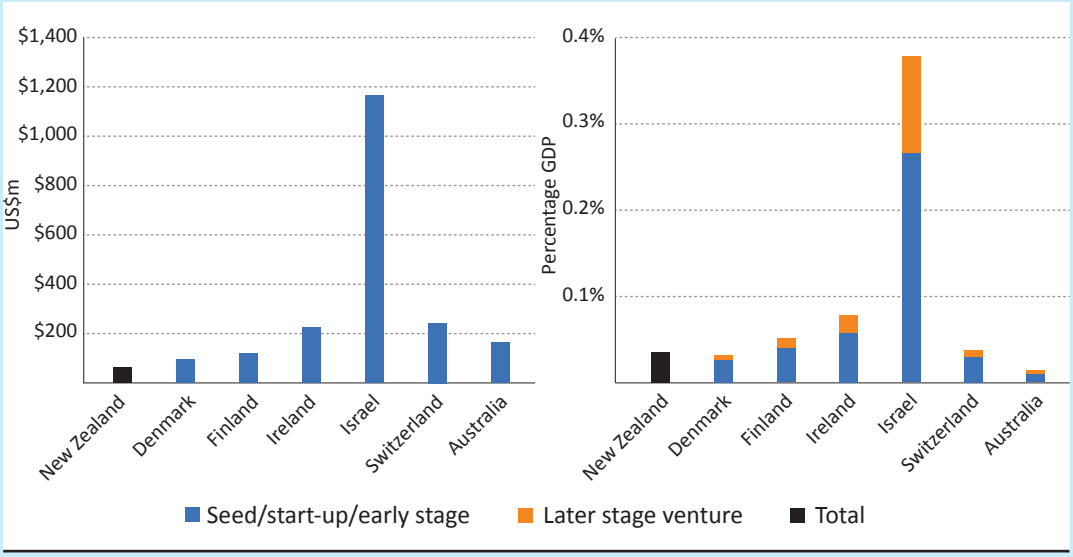
New Zealand has the lowest number of 'tech' start-ups per hundred thousand people (11) compared with the global cities in Start-up Genome's comparison. Being a country, New Zealand will naturally appear slightly lower on this measure than the cities it is compared to, due to the roughly 15 per cent of the population living outside of cities.

Likewise, New Zealand's VC investment is low when compared to the other Small Advanced Economies and Australia. Israel's VC investment is approximately 18 times that of New Zealand. As a percentage of GDP however, New Zealand's VC investment is more than Denmark and Australia, but still lower than other Small Advanced Economies (see Figure 25).

* Activation phase implies fewer than thousand start-ups, restricted local experience and significant numbers of start-ups moving overseas due to local resource gaps.

Focus Box

Figure 25 Venture Capital investments in US$ million and as a per cent of GDP



According to the PwC start investment and the start-up Genome report, New Zealand start-ups do well in terms of:

- Connections with global entrepreneurs;
- Corporate interest and involvement; and
- Having an international customer base.

However, shortcomings for the New Zealand start-up ecosystem include:

- Low-levels of investment, ecosystem value and growth;
- Low-experience levels; and
- High-rates of 'leakage' – in terms of start-ups moving overseas.

Case Studies

MBIE worked with Acil Allen Consulting to prepare a number of case studies of impact, which are included in this report. These were prepared by interviewing researchers and end-users of research and collating data from published documents.

Rocket Lab Launch Complex 1

The past year was one of considerable technical achievements for American company and its wholly-owned New Zealand subsidiary Rocket Lab.

Electron, Rocket Lab's orbital launch vehicle became the first rocket launched from New Zealand to enter space. New Zealand is now one of 11 countries currently able to launch satellites into space from their own territory and the first to launch from a fully private orbital launch range. In January 2018, Rocket Lab successfully reached orbit with its second Electron test launch, deploying three commercial satellites into low Earth orbit.

CASE STUDY 01

Rocket Lab

ROCKET LAB

Electron is powered by Rocket Lab's innovative Rutherford engine – the world's first electric turbopump-fed rocket engine. It is also the first engine to use 3D printing to produce all primary components of the combustor and propellant supply system.

Using its own technology, all components of the rocket – from processing raw materials right through to launching satellites into orbit - were designed and manufactured in-house.

Getting off the ground

Founded in Auckland in 2006 by CEO Peter Beck, Rocket Lab's success represents a lifetime of dreaming and innovating.

Knowing he wanted to work in the aerospace industry, Peter took a toolmaking apprenticeship at Fisher & Paykel which gave him access to top of the line machinery and materials early in his career. In 2001 he started a job at Industrial Research (now Callaghan Innovation) and continued working on his passion – rockets.

Peter decided to start Rocket Lab following a short visit to America where he met with 'aerospace primes' including NASA, and determined that working in the industry wouldn't allow him to achieve his goals of democratising space access for small satellites.

Six months later, Peter quit his role at Industrial Research and Rocket Lab was born.

A mission to remove barriers to commercial space

Reaching space is expensive and slow going, and traditionally, space activities have been in the domain of governments. However new privately run companies like Rocket Lab are making inroads into space activity due to their agile, innovative and cost effective approach to launch, attracting customers who may have previously been locked out of the industry.

Rocket Lab's low-cost service – and the science behind it – is leading the way in removing barriers to commercial space.

The Electron rocket stands at 17 metres tall and can carry a small (150kg) satellite into low earth orbit for approximately US$5.7m, a 'bargain basement' price in aerospace terms. Rocket Lab has found a niche in making and launching affordable rockets frequently – and sees massive demand from the small satellite market. At full production, the company could sustain more than 50 Electron launches a year. For context, there were just 22 launches in the US in 2016 and 82 internationally.

The little engine that could

The Rutherford engine is a significant part of how Rocket Lab has been able to develop the Electron. Designed in New Zealand and manufactured at Rocket Lab's own US facility, development of the 3D printed, electric turbopump-fed Rutherford engine began in 2013, with the first test fire taking place in December of the same year.

"The Rutherford engine was designed from the beginning to be both high performing and fast to manufacture on a mass scale," said Lachlan Matchett, Vice President of Propulsion. "By enabling faster, scalable engine production we speed up production of the whole vehicle. We can print an entire engine in as little as 24 hours." Rocket Lab has produced a total of 40 flight-ready engines to date, and aims to produce another 100 engines by the end of 2018. The Rutherford engine's production scalability is facilitated by additive manufacturing primary components. With a 3D printed combustion chamber, injectors, pumps, and main propellant valves, Rutherford has the most 3D printed components of any rocket engine in the world.

The in-house design also features the use of electrically driven propellant pumps, rather than turbomachinery, further reducing complexity and build-time. This unique approach allows unmatched precision and control of propellent flow and a significant increase in performance through mass savings. Weighing just 35 kg each, nine Rutherford engines propel Rocket Lab's Electron launch vehicle to space powered by a fuel mixture of highly refined kerosene and liquid oxygen.

Why New Zealand?

New Zealand's natural geography, clear skies and small population gives an immediate advantage for launching rockets.

The New Zealand Space Agency, within the Ministry of Business, Innovation and Employment (MBIE), was launched in 2016 but work began in late 2015, when Rocket Lab approached MBIE with its plan to carry out rocket launches.

New Zealand had yet to develop a policy and legal framework to govern space activity but was able to move quickly to meet the opportunity.

While other countries' regimes have been set up for traditional space activity funded by government, with big launches that happen infrequently, New Zealand's regimes also caters for smaller operations largely paid for by private capital. This ensures that the regulations are proportionate to the risks associated with the activity – and the Rocket Lab isn't tied up by excessive red-tape.

Flow on benefits for New Zealand's innovation ecosystem

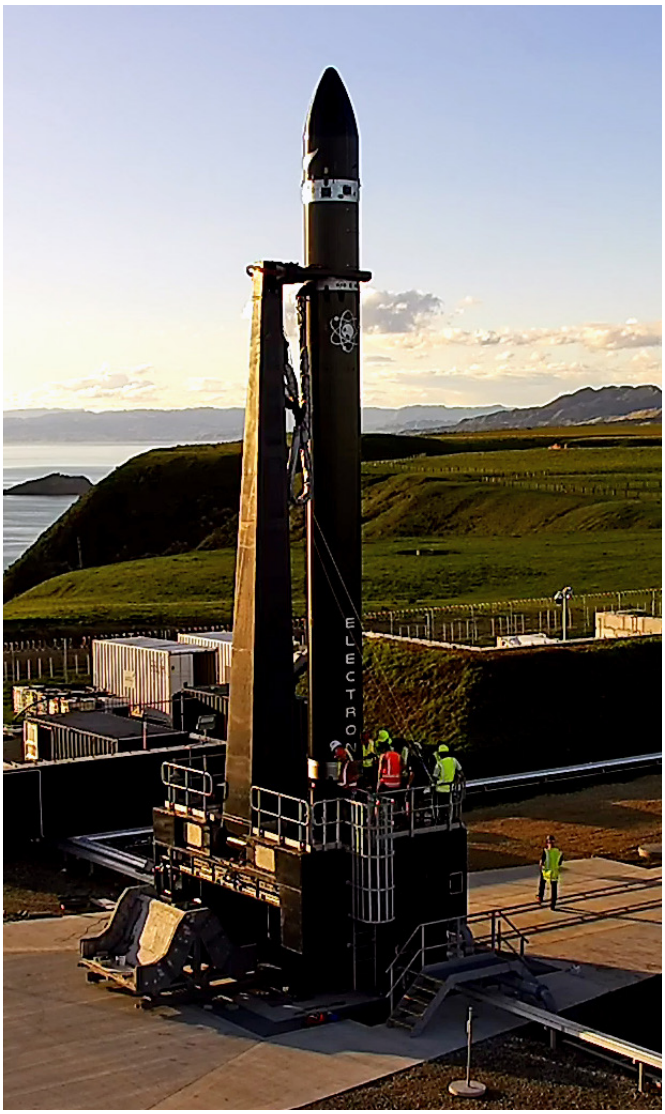
As a front runner in helping to establish a space industry in New Zealand, Rocket Lab's R&D has also had wider benefits for NZ's science and innovation system through its work with research institutions and PhD students.

With around 170 staff across Auckland and Mahia – with the majority of roles working on R&D in some way – the company expects to have a workforce of around several hundred over the next few years. In 2018 the company's efforts will be heavily focused on increasing production to manufacture launch vehicles quickly enough to reach a monthly launch cadence by the end of 2018.

It works closely with a small group of high-tech niche manufacturers in New Zealand as well as the University of Canterbury's Rocketry group. The collaboration has led to the development of an advanced engineering course specialising in aerospace engineering. Rocket Lab is also working closely with Auckland University's Program for Space Systems as students develop a CubeSat to be launched on board an Electron vehicle.

Rocket Lab has also established an annual scholarship for New Zealand students covering up to four years of tertiary fees for study in the fields of science, technology, mathematics or engineering.

The success of Rocket Lab is likely to have a wider impact on science and R&D beyond just the space industry. Other industries and companies are already benefiting from the offshoots of rocket launches, including telecommunications, ICT, manufacturing, navigation systems and more.



Electron 'It's a Test' at Rocket Lab Launch Complex 1

Peter Beck

Electron 'Its a Test' lift off

Perennial ryegrass is the most commonly sown pasture grass in New Zealand. It is an important food source for livestock including sheep and cattle.

CASE STUDY 02

Ryegrass endophytes

25 billion

New Zealand exports over $25b of agricultural products each year, with the majority coming from animals that consume pasture.

RYEGRASS ENDOPHYTES

Endophytes are organisms, usually fungi, that live inside plants. Endophytes can be symbiotic, benign or parasitic. An important reason for the success of perennial ryegrass in New Zealand is its symbiotic relationship with endophytes. These fungi draw nutrients from the ryegrass but in return give resistance to insect pests, tolerance to droughts and protect from overgrazing. These benefits are provided by chemicals the endophytes produce. However, some of these chemicals can also cause animal health problems, particularly a condition called ryegrass staggers.

AgResearch sought new endophyte strains that had well-defined effects on insect pests, grazing animals and ryegrass. The aim was to develop new strains that could be bred or inoculated into the ryegrass. This work would enable seed suppliers to mix and match different combinations of endophyte and ryegrass strains to meet different farmer requirements for different climates or farming systems.

The first new endophyte strain, known as AR1, was commercialised in 2000 through New Zealand seed companies by AgResearch subsidiary Grasslanz Technology. AR1 gave ryegrass tolerance to major pests, particularly Argentine stem weevil. It also improved animal performance as unlike some other strains, it did not produce two specific alkaloid chemicals which were toxic to mammals. AR1 was taken up enthusiastically by New Zealand farmers and was soon included in about 75 per cent of all proprietary ryegrasses sown in New Zealand. Another endophyte AR37, identified in the early 1990s showed further improvements in ryegrass quality, pest tolerance and animal health problems.

The outcomes of this research would not have been achieved without the deep knowledge and research inputs of AgResearch, Grasslanz and the dairy industry. Seed companies played a significant role in getting the technology into a form where it could be marketed and delivered to end users. This included work in relation to seed production and storage to ensure sufficient quantities of viable seed are available to the market.

AR37 was launched at Fieldays in 2006. It is licensed by Grasslanz to PGG Wrightson and NZ Agriseeds. It is being exported to Australia and tested in three other countries. Increasing numbers of New Zealand farmers are sowing ryegrass with the AR37 endophyte. Its improved resistance to drought and major pests including Argentine stem weevil and black beetle is especially important.

The total cost for the AR37 ryegrass endophyte research is estimated to be $12m of public and private funding (2000 to 2006).

Significant benefits have flowed to New Zealand dairy farmers using the AR37 ryegrass, in terms of increased milk solids production per hectare, and less frequent re-grassing. Commercial export revenues have also been achieved through international seed sales.

- *(Top) Porina Caterpillar*
- *(Bottom) Root Aphid*
- *Argentine Stem Weevil*

Research on intensive care practice is particularly challenging. Effect sizes are often small, so good studies need large sample sizes. However, individual intensive care units (ICUs) see few patients. Intensive care patients also arrive at unpredictable times and critical treatment decisions must be made immediately, so clinical trials mean clinicians across a number of intensive care locations must be well-prepared and coordinated.

CASE STUDY 03

Intensive care clinical trials

Empty hospital bed in intensive care

INTENSIVE CARE CLINICAL TRIALS

The Australian and New Zealand Intensive Care Society is a network of doctors involved in intensive care research and practice. They conduct research across many ICUs through their Clinical Trials Group. This enables intensive care research with sufficiently large sample sizes, something New Zealand ICUs would find difficult to achieve alone. Further, research findings are stronger when patients are spread across multiple countries. This case study examines three of the Group's clinical trials: SAFE, NICE_SUGAR, and DECRA.

Clinical Trial 1: SAFE – Saline versus Albumin Fluid Evaluation

Patients in intensive care units (ICUs) often need intravenous fluids. Two options are saline (salt water) and albumin in saline (protein in salt water). Albumin is around 200 times more expensive than saline. It was unclear whether one was more effective in helping save lives than the other. Both were used but albumin was becoming increasingly preferred.

Nearly 7,000 patients needing intravenous fluids were randomly assigned either saline or albumin across 16 ICUs in New Zealand and Australia between 2001 and 2003. The trial showed there was in fact no difference in survival rates generally, and a worse survival rate when using albumin for patients with severe traumatic brain injury. This led to saline being preferred to albumin in ICUs, allowing for cost savings and better outcomes for patients.

Clinical Trial 2: NICE-SUGAR – Normoglycemia in Intensive Care Evaluation-Survival Using Glucose Algorithm Regulation

High blood sugar is common in patients treated in ICUs. Severe cases are associated with increased risk of death. The majority of ICU patients are subjected to some form of blood sugar control. A common approach was to control blood sugar within a tight band, but it was unclear whether this was beneficial.

Over 6,000 patients in ICUs across 42 ICUs in New Zealand, Australia, the US and Canada were randomly assigned to receive either strict blood sugar control or less strict standard control. The trial showed strict control significantly increased the risks of death (27.5 per cent vs 24.9 per cent) and of severe low blood sugar during care. This discovery means that tight blood sugar control is no longer routine treatment in New Zealand. It is estimated that this saves several hundred lives per year. It also reduces costs because tight control uses more resources.

7,000 **6,000**

Clinical Trial 3: DECRA – Decompressive Craniectomy

Decompressive craniectomy is a procedure where part of the skull is removed to relieve pressure on a swelling brain. It is a common procedure in New Zealand. It was unclear whether doing this procedure early in treatment would lead to better outcomes.

Around 150 patients needing treatment for brain swelling in New Zealand, Australia and Saudi Arabia were randomly assigned to receive either standard care or early decompressive craniectomy. The trial found that early craniectomy leads to similar rates of death but slightly higher rates of severe disability in surviving patients. This research may lead to fewer early craniectomies being performed and therefore fewer severe disabilities in survivors. This is estimated to benefit New Zealand by tens of millions of dollars per year.

Benefits and Costs

The Medical Research Institute of New Zealand (MRINZ) has estimated that, over the period 2006-16, the New Zealand Government, through the Health Research Council, invested around $7m in intensive care research. The direct cost savings for the New Zealand healthcare system from the clinical trials were estimated by MRINZ to be well over $150m per year. More importantly, hundreds of people admitted to New Zealand ICU's every year who would have died, have survived as a result of the practice changes that have occurred in response to the findings of these trials.

150

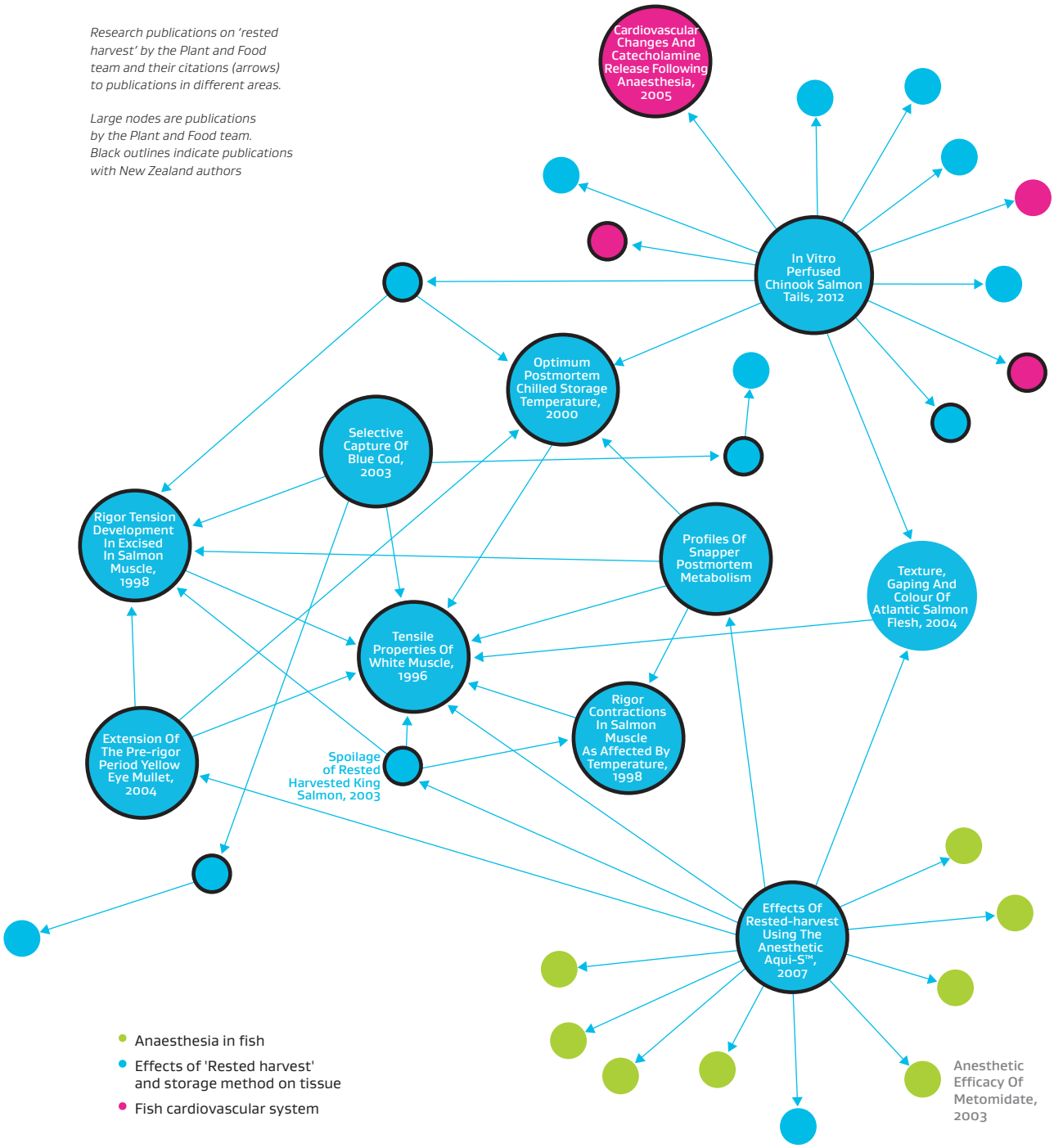
New Zealand has the world's ninth largest Exclusive Economic Zone (EEZ), with some 4.4m square kilometres available for fishing. Consequently fishing plays an important role in the New Zealand economy. Recreational and commercial fishing contributes some 16,000 jobs and about $4.2b in total economic activity. In 2016 New Zealand exported some 288,000 tonnes of seafood products, worth around $1.8b, to 122 countries.

CASE STUDY 04

Sustainable 21st century fishing

Research publications on 'rested harvest' by the Plant and Food team and their citations (arrows) to publications in different areas.

Large nodes are publications by the Plant and Food team. Black outlines indicate publications with New Zealand authors



THE EFFECTS OF 'RESTED HARVEST'

The Plant and Food research team began looking at the effects of 'rested harvesting' on fish in the late 1990s. It was already known that traditional harvesting techniques lead to stress and significant exercise fatigue in fish and this contributes to tissue damage and lower quality seafood products. However, the relationship between these factors was not understood in detail, and it was very hard to perform controlled experiments on fishing boats.

The researchers began studying the effects of rested harvest in the lab. This drew on existing evidence and techniques from the aquaculture industry, where anaesthetics in the water are used to achieve rested harvest in chinook salmon. The monitoring and control possible under lab conditions meant the team could establish the physiological mechanisms which underpinned the effect of exercise on muscle tissue properties.

The significant benefits found in the lab for rested harvest of in hoki and snapper led the researchers to ask 'can we create a wildfish harvesting system which eliminates exercise from the harvest process?'

SUSTAINABLE 21ST CENTURY FISHING

This case study describes research and development undertaken by Plant and Food Research, in collaboration with the University of Canterbury and major fishing companies. Early research by Plant and Food Research led to an improved understanding of fish physiology and the potential effects of different harvesting methods on seafood quality and sustainability. This work led to the development of new handling systems to improve fish condition and environmental outcomes (through by-catch avoided). The current Precision Seafood Harvesting Primary Growth Partnership is developing new fishing methods.

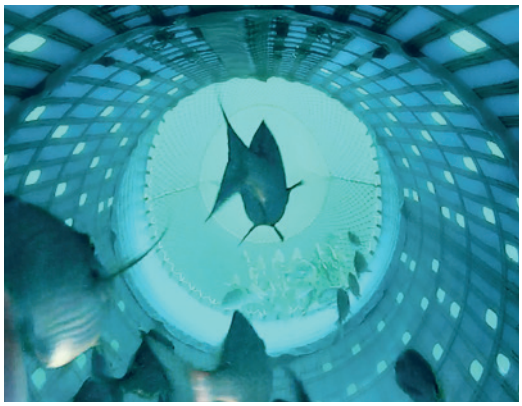
Traditional trawl gear consists of a towed net that captures and channels the captured fish to a 'cod end' where they are collected and then landed on the fishing trawler. The design of the net gear varies depending upon the species and size of fish being targeted by the trawler. Net gear design is also used to try to reduce the amount of by-catch, i.e. fish that are either not wanted for commercial reasons, or fish that is below the regulated minimum size for the species being targeted. The controls on the allowable size of harvested fish are an important measure for ensuring the long-term sustainability of the New Zealand fishing industry.

However, traditional fishing gear creates a number of problems. The current design leads to a strong water flow through the cod end of the gear. The fish captured by the net are therefore either severely fatigued and stressed by their efforts to swim against the water flow or, worse still, injured or killed by being crushed together at the rear of the cod end. These consequences have two impacts. The first is that any by-catch of unwanted fish is likely to be either dead or in poor condition when brought to the surface. Furthermore, even if the by-catch is still alive and released back to the sea from the vessel, it is much less likely to survive if it is in poor condition.

Second, the fish that are being targeted by the fishing operation are often brought on board the boat in a stressed and or damaged condition. The injuries they suffer can significantly reduce their quality, shelf life and hence their value in the market place.

New Zealand has been conducting research aimed at understanding the physiology and biochemistry of harvested fish since the mid-1990s. The objective of this research has been to learn how to reduce the stress associated with the harvesting process. The research has been funded by both Government and the industry.

An important result of this substantial research program has been the development of a new precision seafood-harvesting system. The new trawl gear is designed to provide an environment with a much slower water flow which allows the



captured fish to swim at their own pace and avoid stress and injury.

The new gear is also designed to make it easier for undersized or unwanted fish to escape the net, significantly reducing the amount of by-catch. In addition, the fact that the captured fish are less stressed when brought onto the fishing vessel means that the survival rates of fish returned to the sea are significantly higher.

The fishing industry is collaborating with Plant and Food Research to test, develop and eventually deploy this innovative new technology. Once deployed it is expected that the new harvesting system will enable the wild fish caught by trawlers to match the quality of farmed fish from the aquaculture industry. This improvement will mean that wild caught fish will have the potential to command a price premium, delivering social and economic benefits to the fishing communities through more secure employment and more reliable revenue streams.

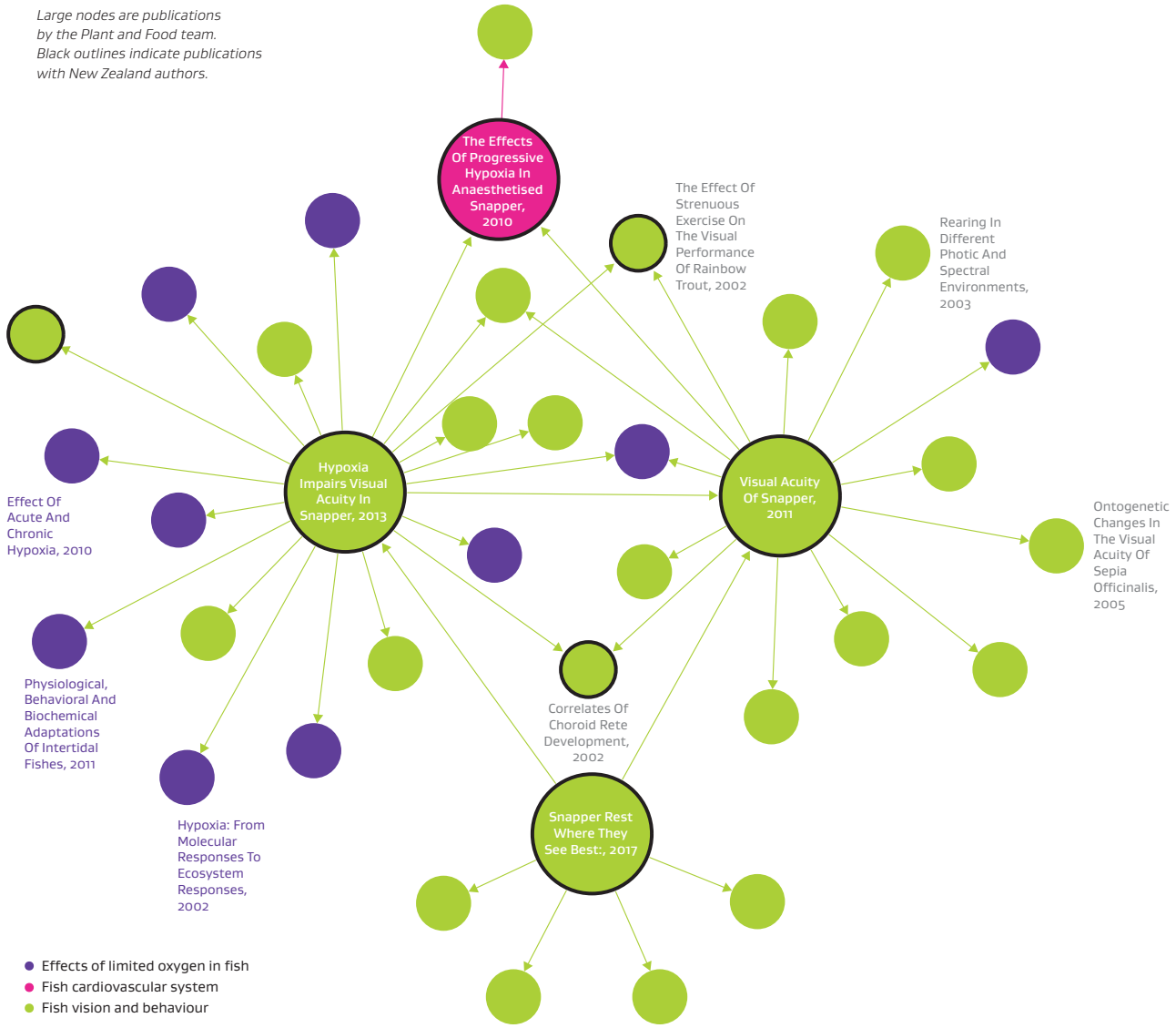
An initial and preliminary estimate of the potential economic benefits to New Zealand of the new fishing technology is $43.6m per annum by 2025. Given that the benefits of this work will be ongoing for many years, the likely return on the investment in the research would appear to be very good.

Importantly, operators are going to have to change their on-board handling practices to make sure that the fish are not damaged or excessively stressed during the later stages of the fishing process. Consequently, an education and training program to change the seafood industry's mindset, culture and practices from a one that is focussed on volume to one with an emphasis on quality and value is an important element of the deployment of the new system.

The new fishing technology is expected to deliver environmental benefits through the reduced mortality rates of the trawlers' by-catch for in-shore species of fish. This reduction in mortality would improve the sustainability of the in-shore trawling industry and strengthen the broader New Zealand community's acceptance of the trawler firms' license to operate.

Research publications on 'fish vision' by the Plant and Food team and their citations (arrows) to publications in different areas.

Large nodes are publications by the Plant and Food team. Black outlines indicate publications with New Zealand authors.



INVESTIGATING FISH VISION

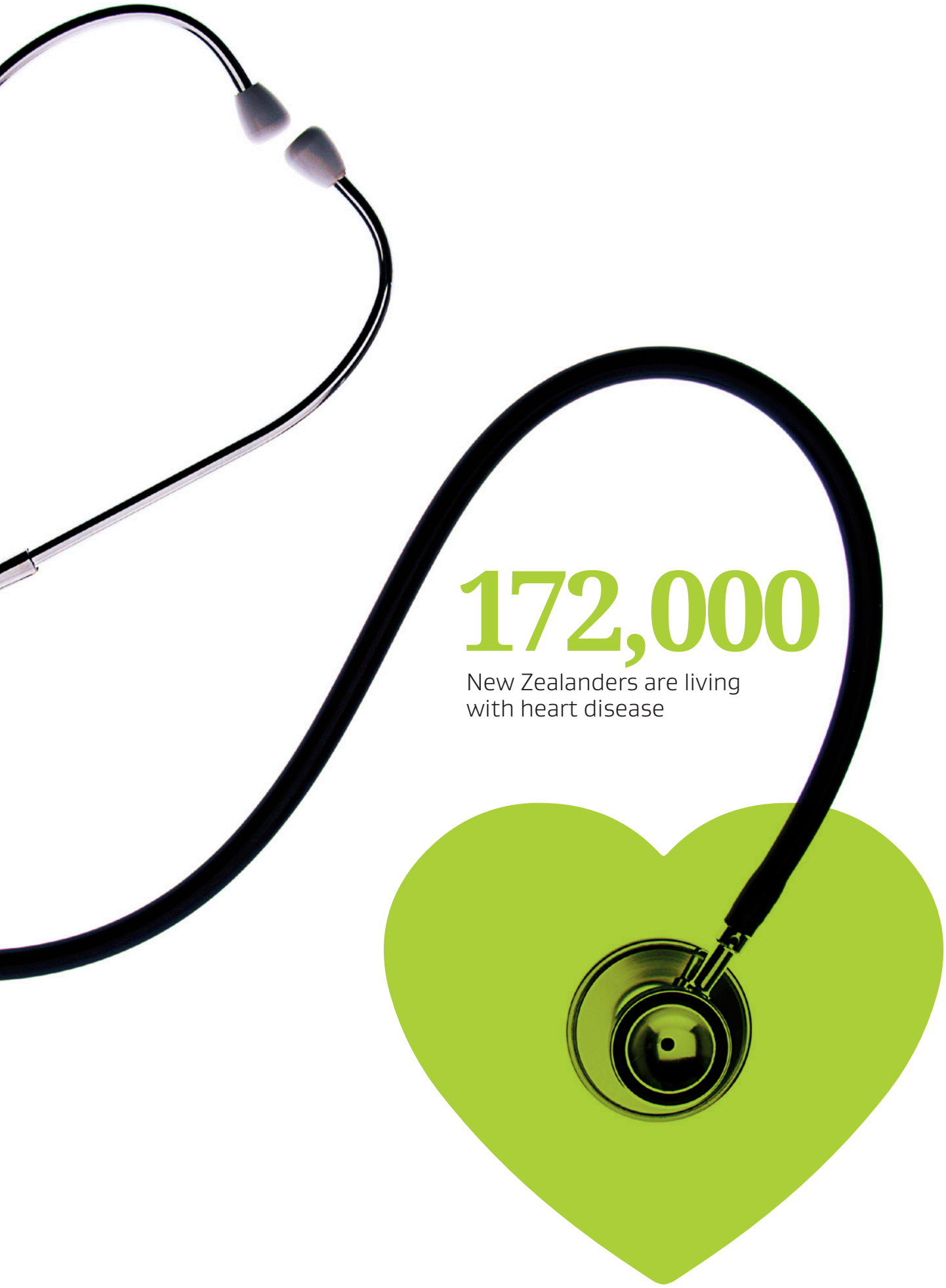
During the development of the fishing technology, the Plant and Food team noticed snapper reacted to visual aspects of their environment, including colour. This prompted the researchers to start investigating fish vision. Initially the researchers wondered if they could send visual signals which would influence fish behaviour, by changing the appearance of parts of the fishing gear. For example, could the 'escapement' holes be made more visible to enable by-catch species to get away more easily?

This led to more fundamental research into how different fish species' visual acuity had evolved to suit the light conditions of their habitat. Most recently the team has shown how this visual acuity in turn influences fish behaviour, leading to the 2017 paper 'Snapper rest where they see best'.

Cardiovascular disease (CVD) is a leading cause of death and serious illness. In the past, doctors relied on measurements of blood pressure and cholesterol, as indicators of cardiovascular risk. While it has been known for some time that other factors are also important in the diagnosis of cardiovascular risk, it is only recently that doctors have been able to accurately take these into account. Professor Rod Jackson and his colleagues at Auckland University have undertaken the research that underpins a web-based analytical tool which provides doctors with a quantitative assessment of cardiovascular risk and suggests appropriate treatment. The web-based technology has been commercialised by Auckland-based Enigma Solutions. Research by Professor Jackson's group has been supported by the Health Research Council.

CASE STUDY 05

Better heart disease risk assessment



172,000

New Zealanders are living with heart disease

BETTER HEART DISEASE RISK ASSESSMENT

The Heart Foundation reports that 172,000 New Zealanders are living with heart disease and that 33 per cent of deaths annually are caused by cardiovascular disease (CVD). The Framingham Heart Study from 1948 provided an analysis of the common characteristics that contribute to CVD. This study of around 5,000 participants from the US town of Framingham provided patient data over an extended period of time, commencing before CVD symptoms appeared. This data was used to develop risk-prediction equations that take a number of relevant factors into account. However, the equations were difficult to use in clinical practice. As a result, doctors continued to rely on just two indicators of CVD risk—blood pressure and cholesterol levels.

Professor Rod Jackson's research group at the University of Auckland developed ways of making the Framingham results useful to doctors. Initially this assistance took the form of a one-page colour chart. While charts led to an improvement, GPs didn't use them as much as hoped because they often misplaced them.

Professor Jackson subsequently developed an online system which provides doctors with an on-the-spot assessment of CVD risk and also suggests appropriate treatment. In addition, the system collects anonymised data which allows Professor Jackson and his colleagues to track the subsequent health of patients. This data provides the evidence for further refinement of the system. New Zealand is well-suited to this approach because individuals have unique identifiers, allowing the risk assessments to be linked to actual health outcomes.

There is international epidemiological evidence that supports identifying people at high risk of CVD and treating them with lifestyle and drug-based interventions. If fully implemented, this approach could reduce future CVD events by over 50 per cent. However, communicating risk information to patients is important but difficult. Patients who have a high risk of heart disease are only able to realise they need to change their lifestyle if they properly understand their risk. In 2008, Professor Jackson's colleagues, Drs Sue Wells and Andrew Kerr, developed Your Heart Forecast, a tool to communicate information about heart risk and help change behaviour. Visualising information can make it much easier to understand – important when communicating difficult information like risk over a lifetime.

Professor Jackson and his colleagues have worked with Auckland-based Enigma Solutions to supply PREDICT, Your Heart Forecast and other software systems for use by doctors in analysing CVD risk and providing suggested treatment. This software also collects anonymised patient data to inform refinement of the risk equations by the Jackson group and further development of the Enigma product.

Benefits and costs

The costs of the research and development described in the case study are estimated at approximately $9m in nominal terms since the year 2000. Most of this funding has been provided by the Health Research Council.

The impact of this research has been:

- A better understanding of the factors which predict future CVD;
- Improved targeting and treatment of patients at high risk of CVD;
- More effective use of health funding in the prevention of CVD;
- The development of PREDICT and other web-based clinical decision support systems for assessing CVD risk and recommending preventive interventions;
- Generation of a research database linked to the web-based clinical tool that provides the evidence base for further refinement of the CVD risk-prediction equations;
- Sales and exports by Enigma Solutions.

Potential size of benefits

The costs of CVD for the health system are substantial. A 2010 study of health care costs related to CVD and diabetes in the Counties Manukau District Health Board found that, for a population of around 473,000 in this district, 20,357 people were living with CVD. The combined cost of pharmaceutical claims, laboratory costs and hospital discharges was reported to be more than $110m in 2008. Improved targeting of CVD treatment has the potential to make this health care spending more effective.

The estimated burden of disease for CVD sufferers, in terms of premature death and disability, are an order of magnitude higher than the direct health system costs. An Australian study estimated the total costs of CVD, including the disease burden, at over A$108b in 2004. Assuming a similar incidence of disease in New Zealand, and adjusting for inflation and population growth, this gives an estimated total cost of CVD in New Zealand today of NZ$38b per year.

Due to the improved diagnosis and treatment advice achieved by the new tool, the researchers expect a 30 per cent reduction in cardiovascular events as a result if fully adopted by New Zealand clinicians. This suggests the benefits could very substantially outweigh the estimated costs of this research and development ($7m).

The PREDICT tool could not exist without the data provided by the Framingham heart study, and other overseas clinical trials, but the cost of these is not included. This partly explains the extremely favourable estimated benefit-cost ratio. On the other hand, this high value also demonstrates that the costs of cardiovascular disease are massive, risk factors are well-understood and targeted treatments are effective, so that ensuring the existing evidence base is fully implemented can be very beneficial.

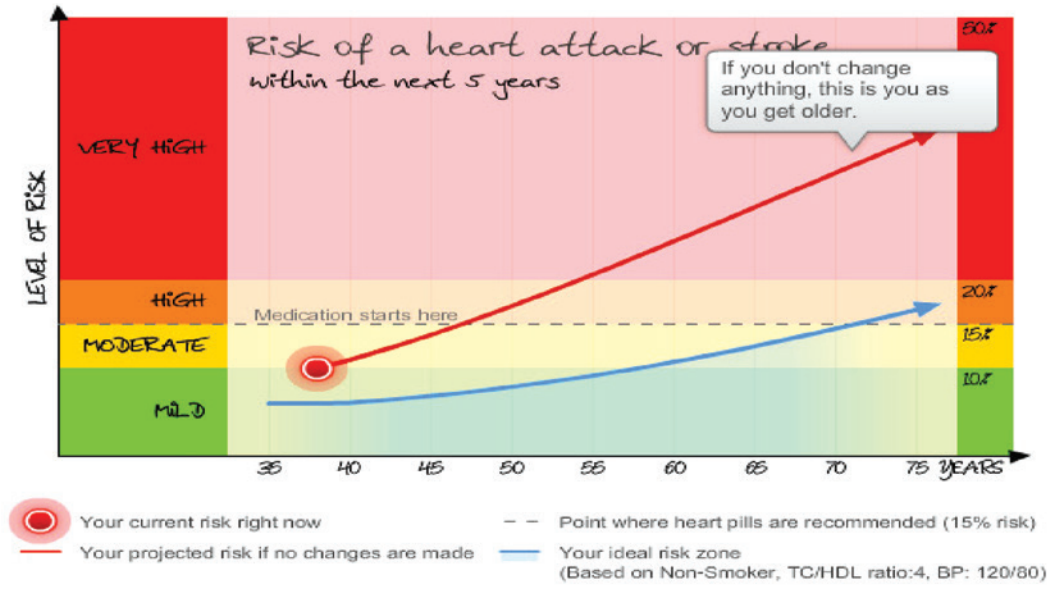
$38b

Estimated cost of CVD in New Zealand today is NZ$38b per annum

30%

Researchers expect a 30 per cent reduction in cardiovascular events as a result of its full uptake by New Zealand clinicians

Figure 26 Screenshot from 'Your Heart Forecast' tool



Investment

Investment

The data in this section show how much is invested in research, science and innovation, by whom, and how this is changing over time. It benchmarks rates of investment internationally to reveal New Zealand's relative R&D intensity.

To interpret the data properly, it's important to understand how we use the terms 'funding' and 'expenditure' in this section:

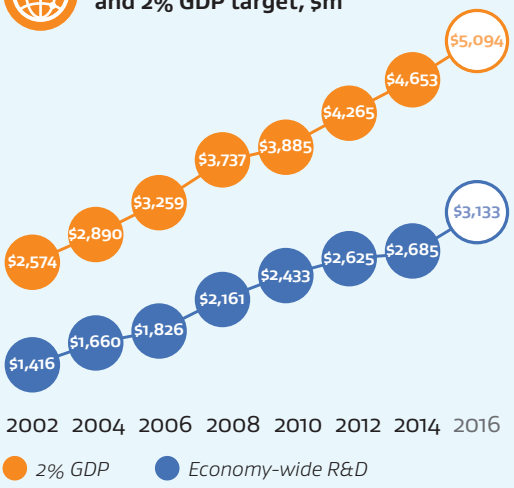
› 'R&D funding' refers to who paid for the research

› 'R&D expenditure' refers to who performed the research

The R&D funder and performer will often, but not always, be the same entity or sector.

Government target is to raise economy-wide R&D to 2% GDP

Economy-wide R&D spending and 2% GDP target, $m

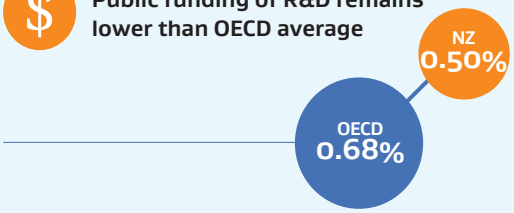


Business R&D is growing strongly

Business expenditure on R&D, $m

Publicly funded R&D will grow significantly following Budget 2018

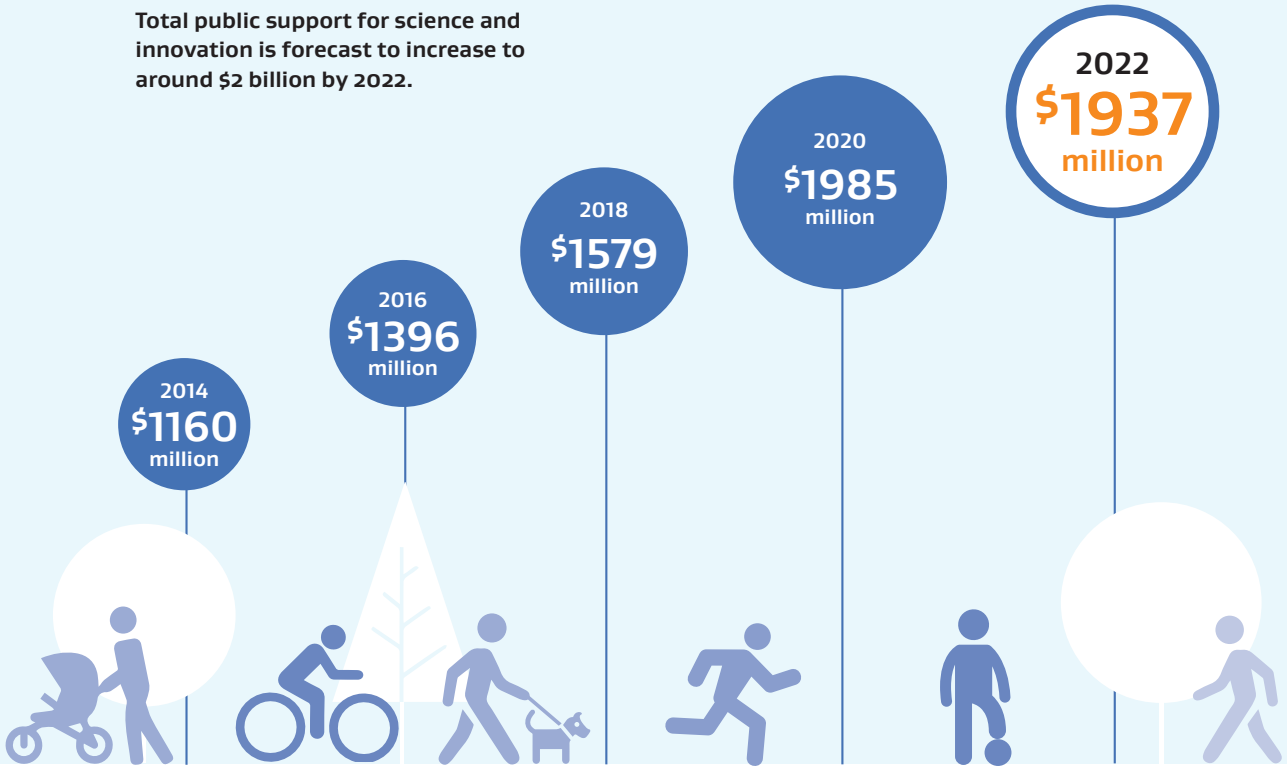
Public funding of R&D remains lower than OECD average



Business, Government and Higher Education all performed more R&D in 2016.

	2014	2016
Business	$1246m	$1602m
Government	$622m	$654m
Higher Education	$817m	$877m
Total	$2685m	$3133m

Total public support for science and innovation is forecast to increase to around $2 billion by 2022.

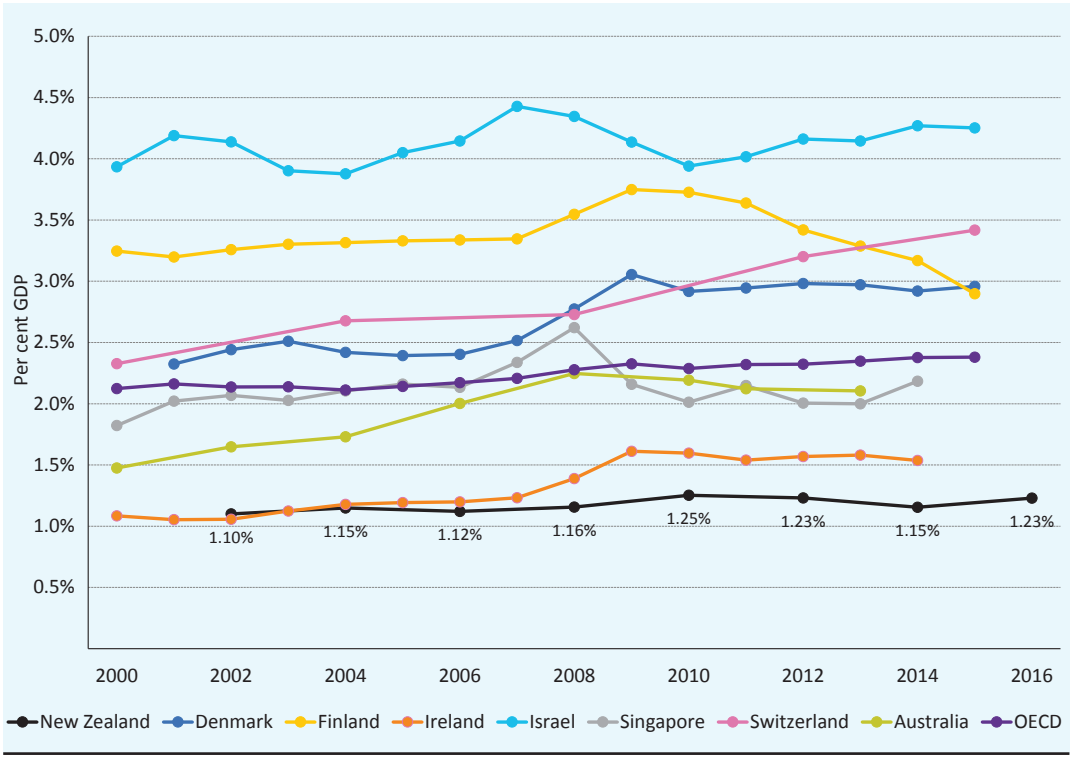


TOTAL R&D EXPENDITURE

This measures expenditure on R&D across the New Zealand economy and is the total of expenditure in business, higher education and government. R&D is defined as "creative and systematic work undertaken in order to increase the stock of knowledge – including knowledge of humankind, culture and society – and to devise new applications of available knowledge".[13]

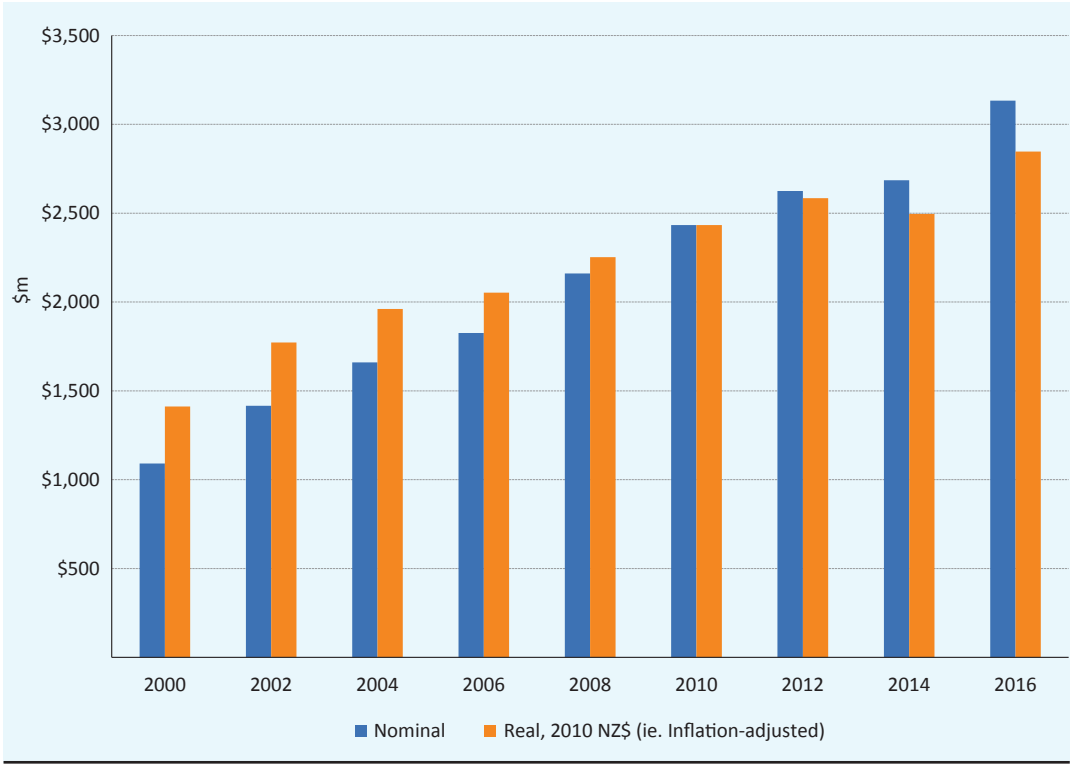
R&D intensity (R&D as a proportion of GDP) indicates the share of the economy's activity directed towards R&D. International research has found that investing in R&D contributes to a country's productivity gains, both through stimulating innovation and sustaining a workforce with the expertise to understand and make use of globally-generated knowledge and ideas.

Figure 27 Total Expenditure on R&D as a proportion of GDP



New Zealand's R&D expenditure was 1.23 per cent of GDP in 2016, broadly similar to levels seen for the last eight years. It is the lowest of the Small Advanced Economies and Australia. Over the long-term, gross expenditure in R&D is growing marginally faster than GDP.

Figure 28 Total expenditure on R&D, nominal and real (inflation-adjusted)



New Zealand's expenditure on R&D grew by 17 per cent between 2014 and 2016 to $3.1b, and has nearly tripled since 2000 in nominal terms (it has doubled in real-terms, i.e. after adjusting for inflation). Likewise, except for a minor downturn between 2012 and 2014, real expenditure (inflation adjusted) grew by approximately 80 per cent between 2000 and 2016. Overall, gross expenditure in R&D is growing faster than inflation.

R&D EXPENDITURE BY FUNDER AND RECIPIENT

Figure 29 shows that most government funding is directed towards higher education and government research (mainly CRIs) rather than to business. Business funds the majority of R&D which it performs.

Figure 29 R&D by funder and performer (recipient)*

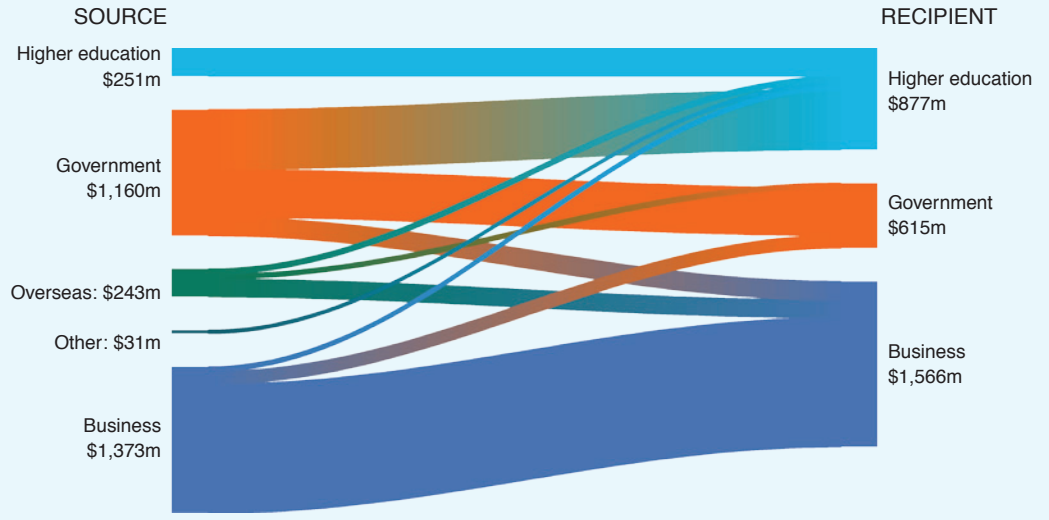
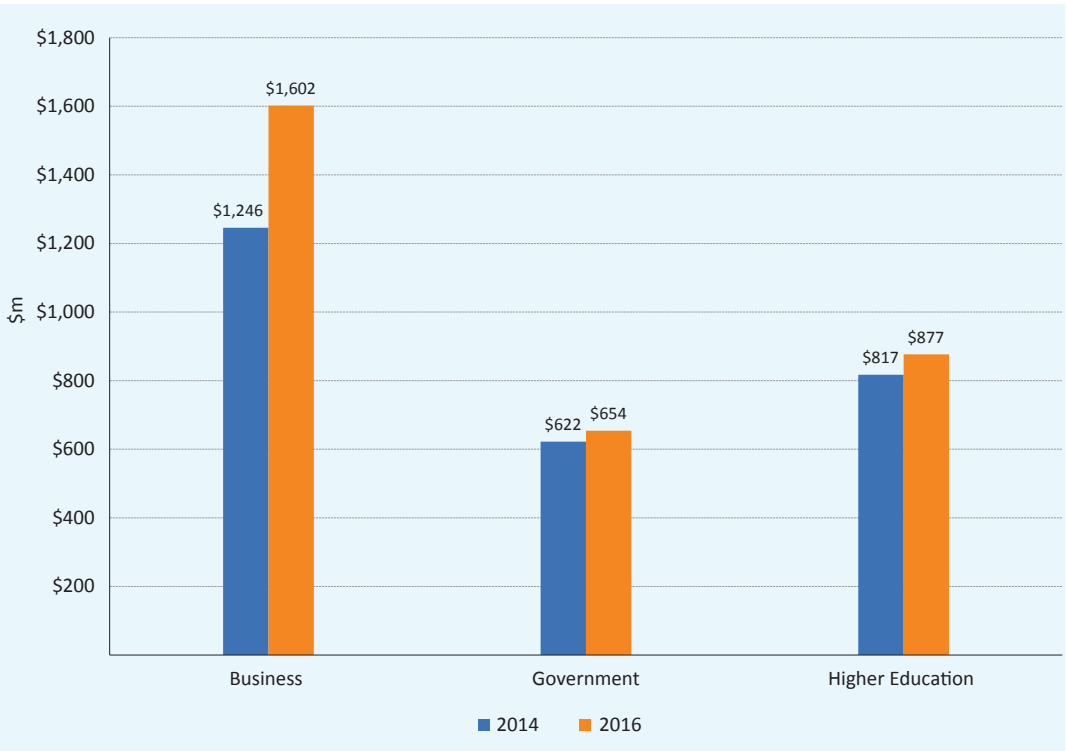


Figure 30 shows R&D expenditure by sector. All of three sectors have significantly grown in 2016 compared to 2014. Business expenditure on R&D grew the most, mainly due to an increase in the expenditure undertaken by firms with more than 500 RME.

Figure 30 Business, Government and Higher Education expenditure on R&D in 2014 and 2016



* Note the numbers shown for Government and Business research expenditure on the right hand side of Figure 29 do not exactly match those elsewhere in the report. They exclude $75m of research funding for which we do not have a full breakdown due to data confidentiality rules.

Government Expenditure on R&D

R&D performed by government is relatively high among Small Advanced Economies, at 0.26 per cent of GDP comparable to that of Finland and the OECD average*. This is partly a result of the CRI model which directs roughly one-sixth of government R&D funding to CRIs.

Figure 31 Government expenditure on R&D as a proportion of GDP

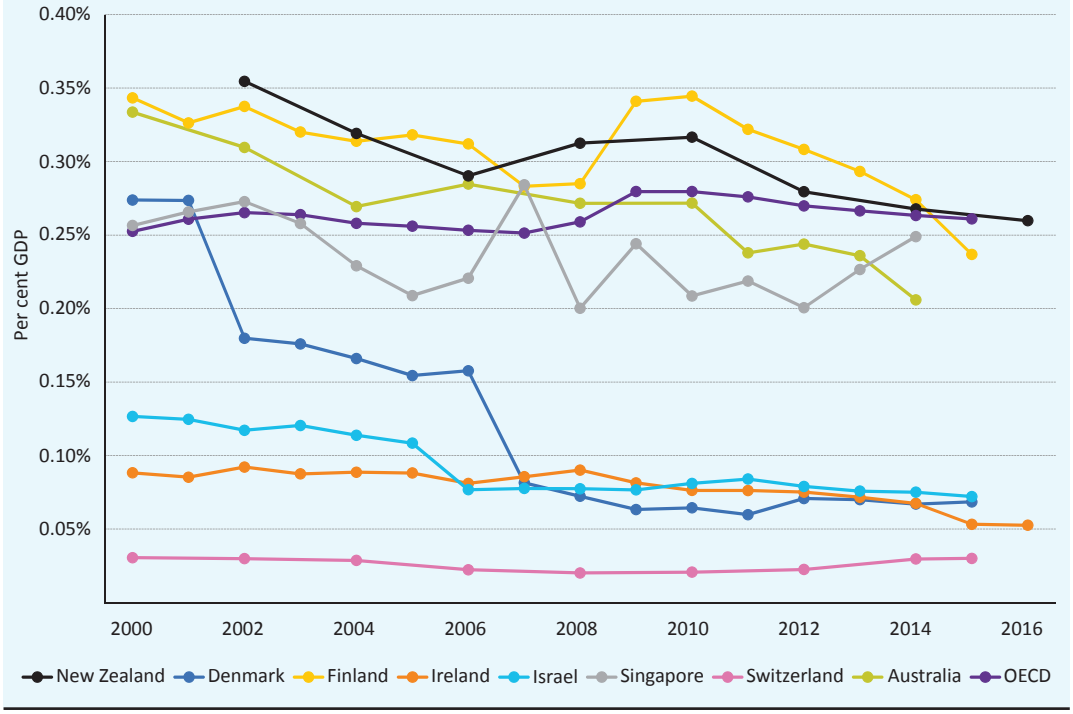
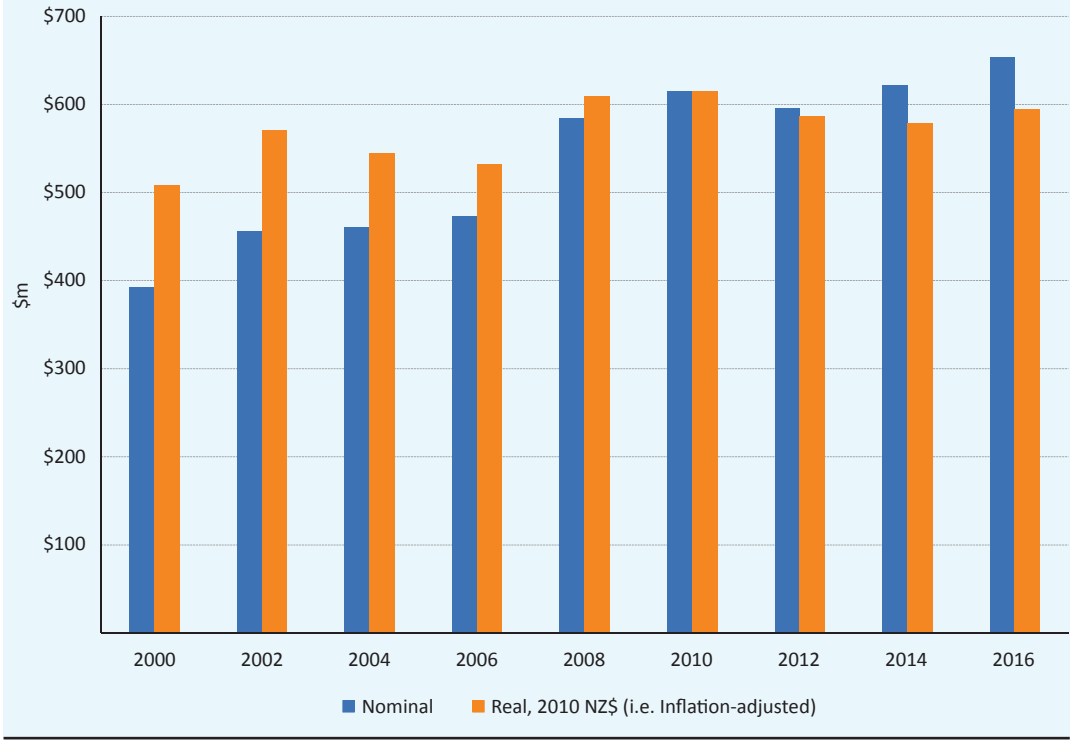


Figure 32 R&D performed by Government, nominal and real (inflation-adjusted)



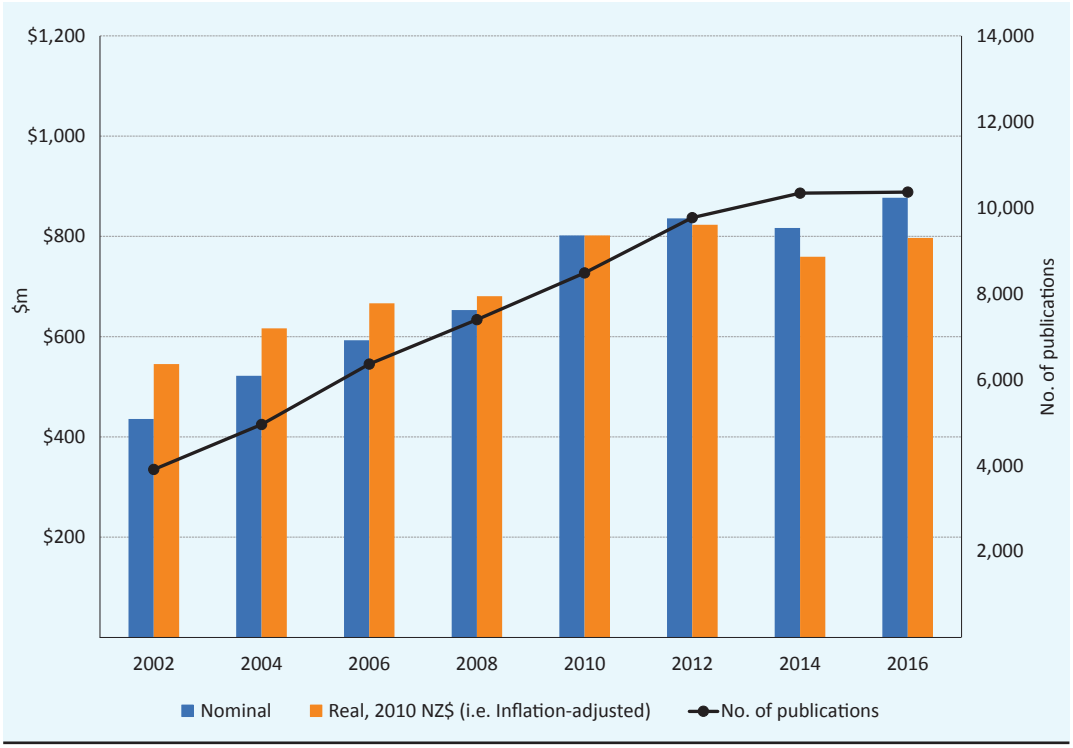
* These figures are given in current purchasing power parity US dollars, which allows a fair comparison across countries. This does not adjust for the reduction in real spending power due to inflation.

Higher Education Expenditure on R&D

Around one-third of New Zealand's total expenditure on R&D occurs in universities and other tertiary institutions, which produced 10,364 research publications (82 per cent of New Zealand's total publications) in 2016[14]. Tertiary sector research is integral to the education system. It allows teaching staff to stay at the forefront of knowledge in their field. Involving students in research develops the next generation of scientists and innovators.

We have been doing well on outputs per dollar of research funding, being top among Small Advanced Economies (see Figure 2).

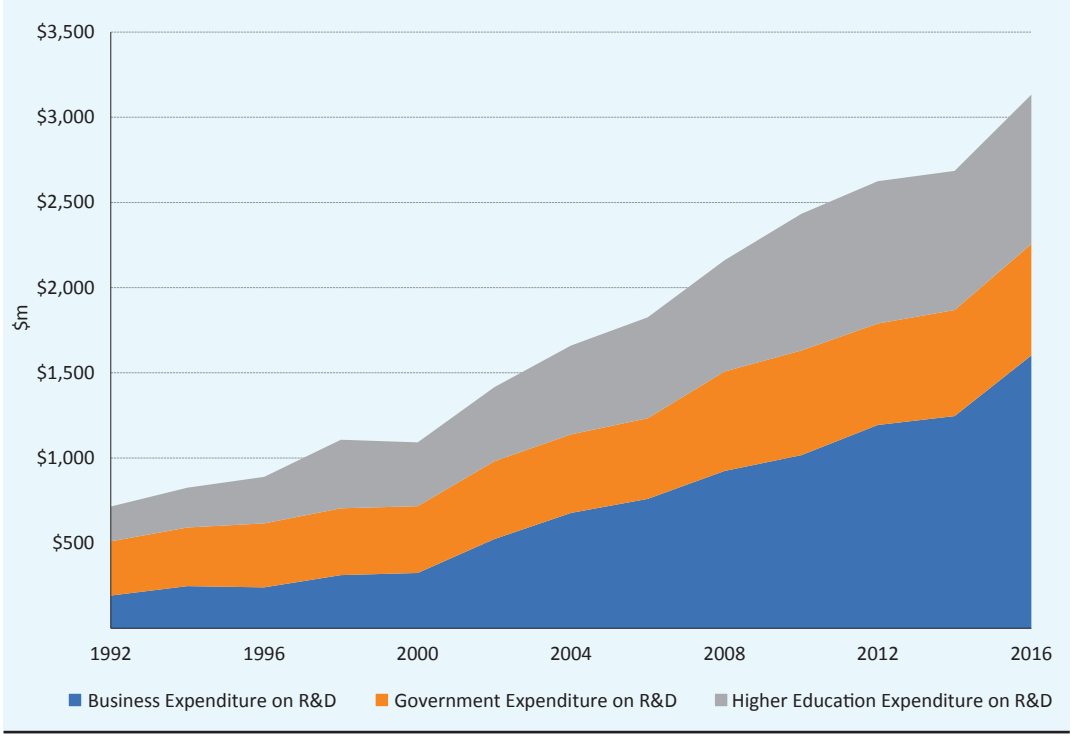
Figure 33 Higher education expenditure on R&D, nominal and real (inflation-adjusted) and number of higher education publications



New Zealand's Higher Education research expenditure grew in real terms between 2002 and 2012, but has fallen slightly in real terms since 2012 (Figure 33). New Zealand's Higher Education research expenditure as a proportion of GDP is comparable to the OECD average (and to Ireland's) but lower than the other Small Advanced Economies.

Figure 34 shows the (nominal) growth of R&D expenditure by sector over the last 25 years. It reveals that business expenditure has contributed the most to growth and has increased from 30% of total R&D in 2001 to 51% of total R&D in 2016.

Figure 34 R&D growth by sector of performance, nominal NZ $

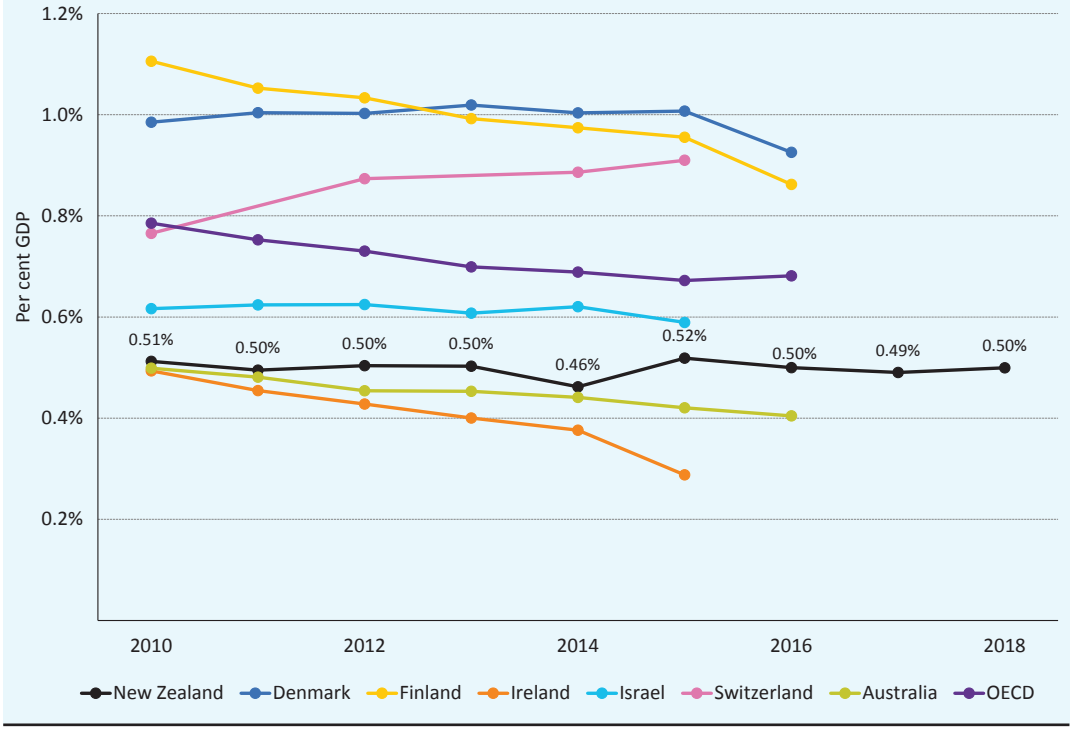


PUBLIC FUNDING OF R&D

Public funding of R&D measures all government outlays on R&D, whether the expenditure itself occurs within government or in the private sector.

Governments fund R&D because the benefits from the knowledge generated extend beyond those performing the research. Individual firms are unlikely to be able to fully capture these benefits, leading to under-investment in R&D without government support. R&D can also help solve societal and environmental challenges.

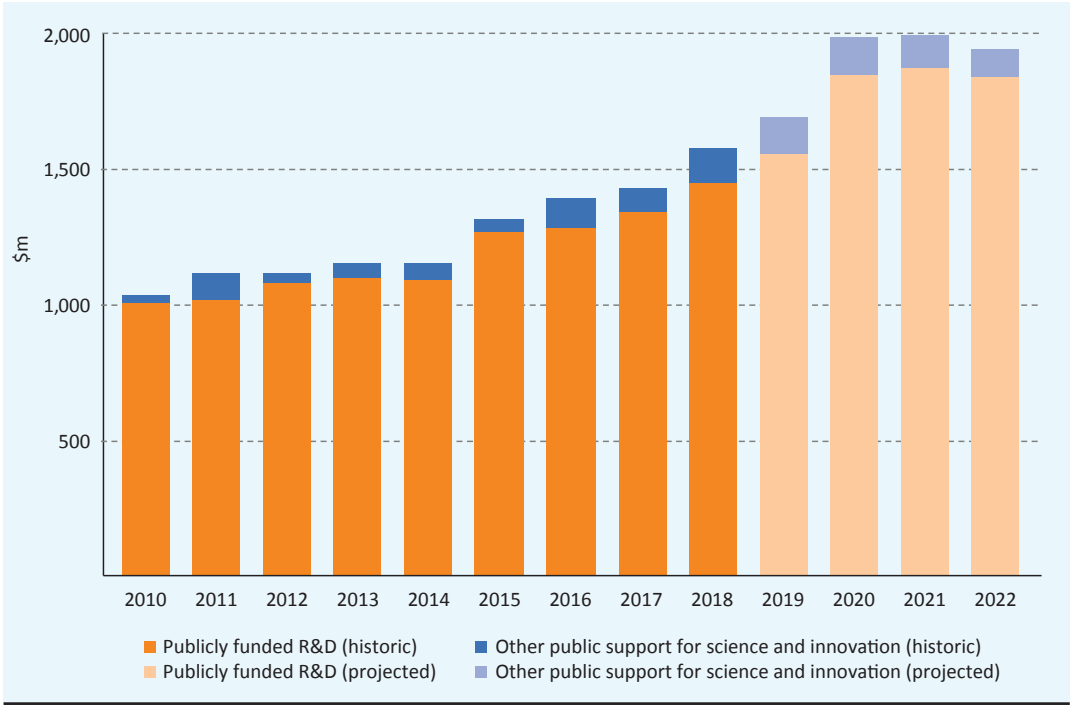
Figure 35 Public Funding of R&D as a proportion of GDP



New Zealand's public funding of R&D as a proportion of GDP is somewhat lower than the OECD average, although the gap with the OECD is closing due to a consistent fall in the OECD value over recent years. New Zealand leads Australia and Ireland on this indicator*, but is still significantly behind Denmark and Finland (which are among the highest in the world).

Figure 35 includes R&D which meets the formal definition required by the OECD. This excludes some other government support for science and innovation, such as assistance for business innovation, administration of science contracts and efforts to improve public engagement with science. Adjusting for these items gives government's total support for science and innovation (Figure 36).

Figure 36 Total public support for research, science and innovation (including projected future funding based on Budget 18 figures)**



* Ireland's decline on this indicator is likely to be driven by its high GDP growth.

** The projected 2019-2022 figures show the four-year funding total appropriated for research, science and innovation in Budget 2018. The timing of future expenditure is uncertain so the yearly expenditure profile is likely to be different to that shown here, and the decline in 2022 is not significant

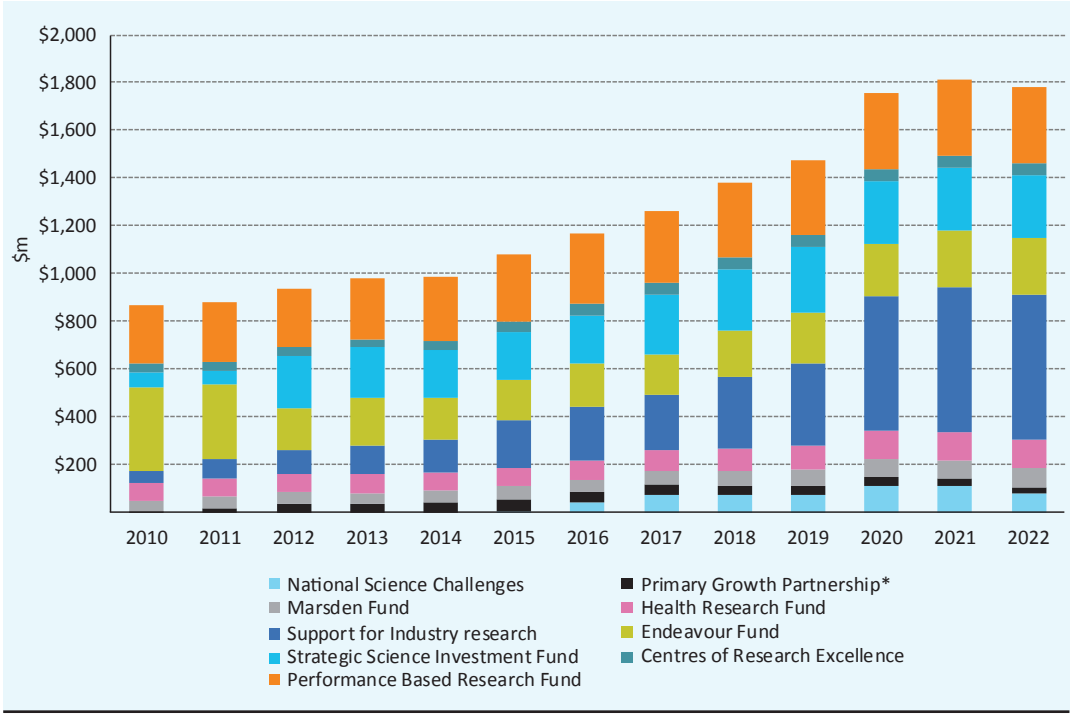
Public funding by mechanism

This measure breaks down public funding of R&D (and some related activities) by the primary funding mechanisms used.

The funding mechanism affects the field and horizon of research (i.e. close to or far from market) and recipients of funding. This data reveal the most significant funding mechanisms and how the focus of government funding has evolved over time.

Historically, the largest funding mechanisms have been the Performance-Based Research Fund†, institutional block-grant funding for the CRIs and MBIE's contestable research funding. Support for business innovation has grown into a major investment area in recent years, particularly since the establishment of Callaghan Innovation in 2013, which administers this funding source. The share of funding going to National Science Challenges has been growing as they have become established. Support for industry research is forecasted to have strong growth over the next three years due to the re-introduction of the R&D tax incentive.

Figure 37 Public funding through key mechanisms, actual and forecast (2018 refers to financial year 17/18)**



* Note that the Primary Growth Partnership is becoming the Sustainable Food & Fibre Futures Fund for new research contracts from 2018.

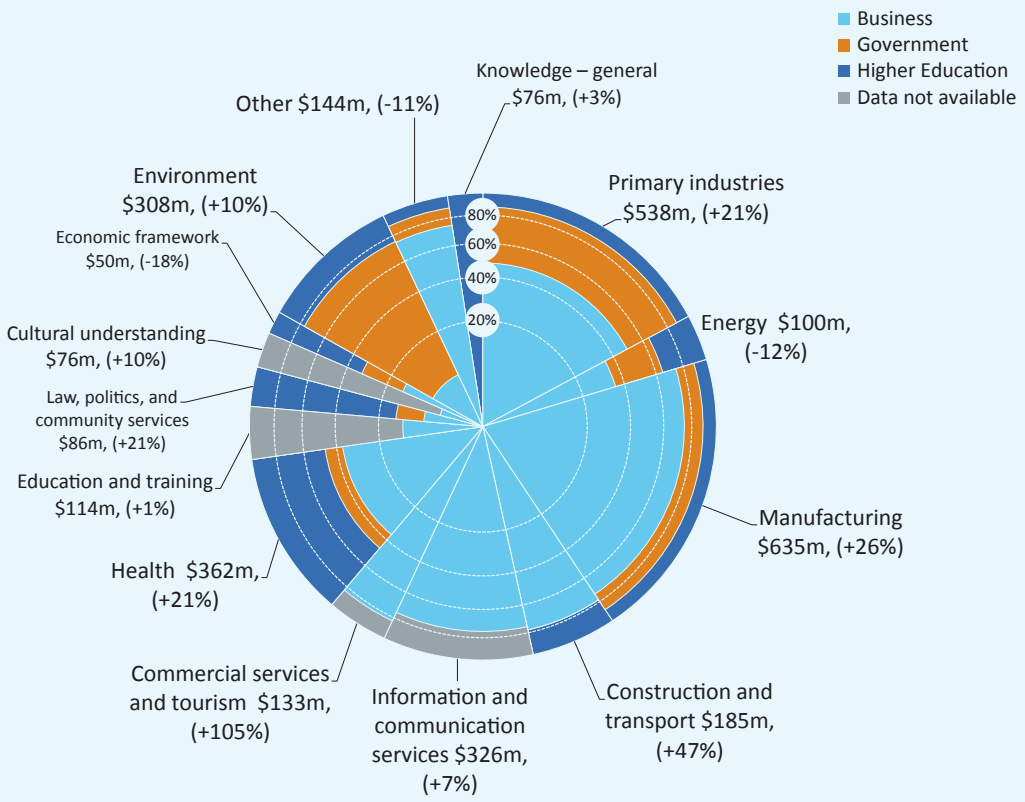
** The projected 2019-2022 figures show the four-year funding appropriated through Budget 18 for key research, science and innovation funding mechanisms. The timing of future expenditure is uncertain so the actual yearly expenditure profile for each fund may differ from that shown here, and the decline in 2022 is not significant.

† The Performance Based Research fund does not directly purchase research. It is a funding mechanism for the tertiary sector that provides financial and reputational incentives for high-quality research and research-led teaching and learning.

R&D expenditure by purpose of research and sector of expenditure

This indicator shows how New Zealand's research expenditure is split by purpose and sector of expenditure (Government, business or higher education). The areas on the chart are proportional to dollars spent in 2016. The percentage values indicate the change in values since 2014.

Figure 38 Expenditure on R&D by purpose of research and sector of expenditure, 2016



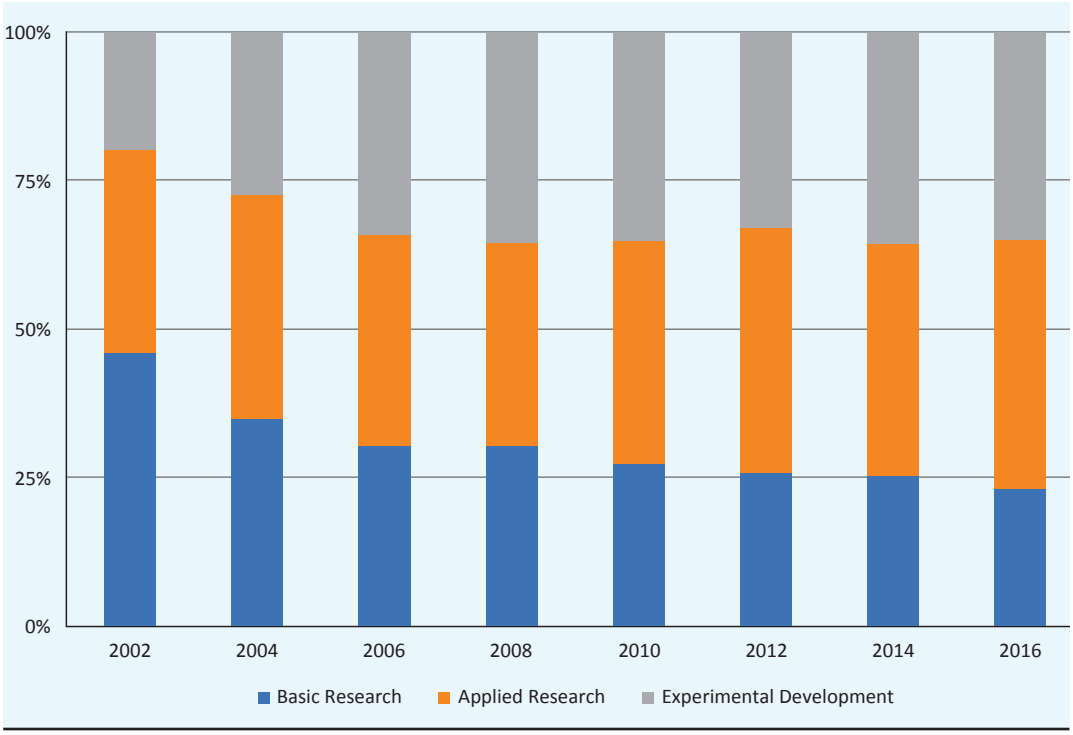
Key Points

- The overall composition by purpose and sector is only changing slowly. Manufacturing and Primary Industry remain the largest sectors.
- Between 2014 and 2016 information and communication services witnessed growth by $21m in absolute terms or seven per cent in percentage terms. Manufacturing had the strongest growth in R&D in absolute terms (+$133m), increasing by 26 per cent.
- Primary industry R&D also grew $94m or 21 per cent. This was driven by a $71m increase in business expenditure with $22m from government expenditure. A significant portion of primary industry R&D ($214m) is performed in government. At 33 per cent the proportion of New Zealand Government R&D expenditure in primary industries is among the highest in the OECD[15].

R&D expenditure by type of research

This measures the proportion of funding that goes into basic research, applied research, and experimental development (closest to market).

Figure 39 Proportion of research expenditure by type



Applied research expenditure has increased in real terms since 2002 and accounts for the highest proportion of New Zealand's R&D spend.

New Zealand spends a similar proportion on basic and applied research to most other Small Advanced Economies, but spends significantly less on experimental research. For example, Israel (77 per cent), Singapore (48 per cent) and Ireland (48 per cent) have been consistently spending a higher proportion on experimental research.

Infrastructure

Research infrastructure refers to large-scale equipment, capability, collections and databases which support scientific research. Some research infrastructure currently receives direct government support:

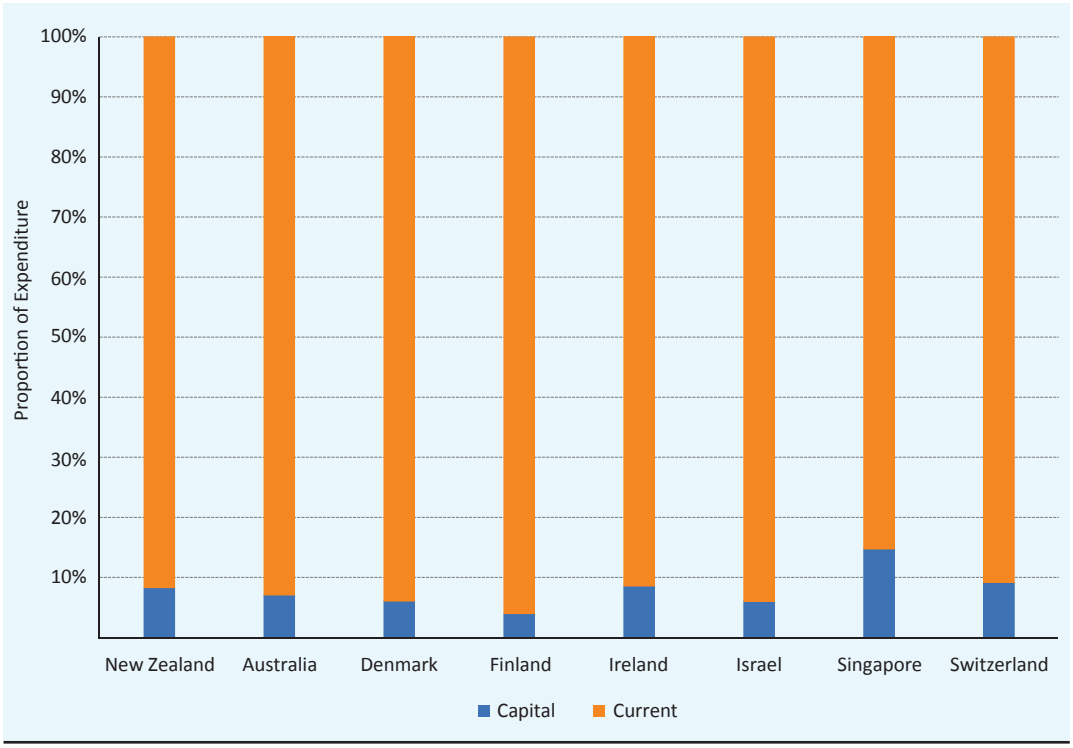
- Advanced Genomics Research Platform – a collaborative national platform for genomics research
- Enhanced Natural Hazards Monitoring – Geonet's hazard monitoring and warning capability
- Research Vessel Tangaroa – a ship used for ocean research, including Antarctic voyages
- Contribution to the international Square Kilometre Array project – the world's largest radio telescope, consisting of thousands of individual telescopes, to be built in Australia and South Africa
- Research and Education Advanced Network NZ – a high-speed data network for researchers
- National eScience Infrastructure – high-performance computing for researchers
- Australian Synchrotron – source of extremely bright light used for imaging and analysing samples of material in a wide range of research fields
- Nationally Significant Collections and Databases – a wide range of information held by the CRIs, including geological, marine, freshwater, atmospheric, climate, animal and plant materials, observation databases, and geospatial datasets.

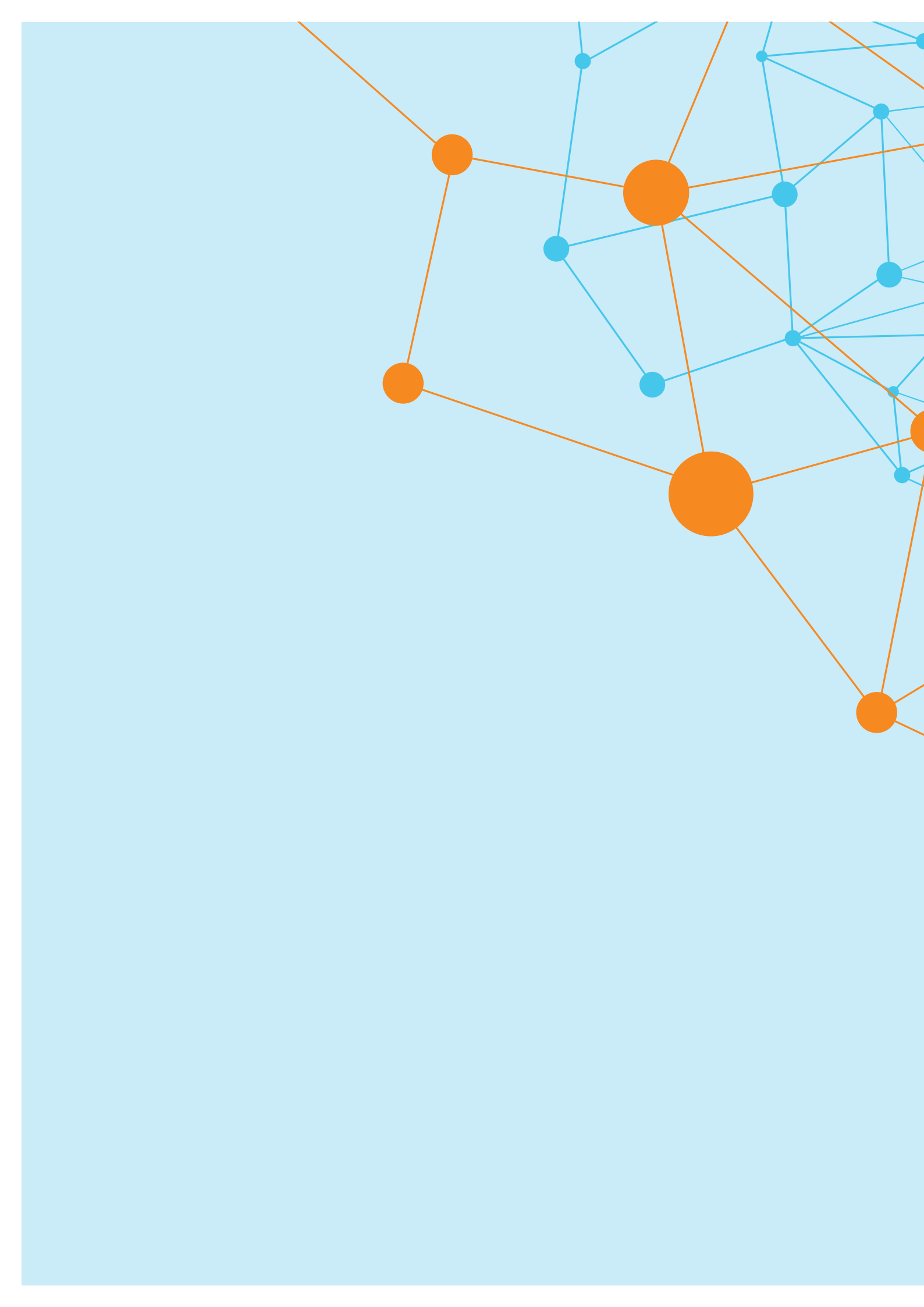
Capital research expenditure

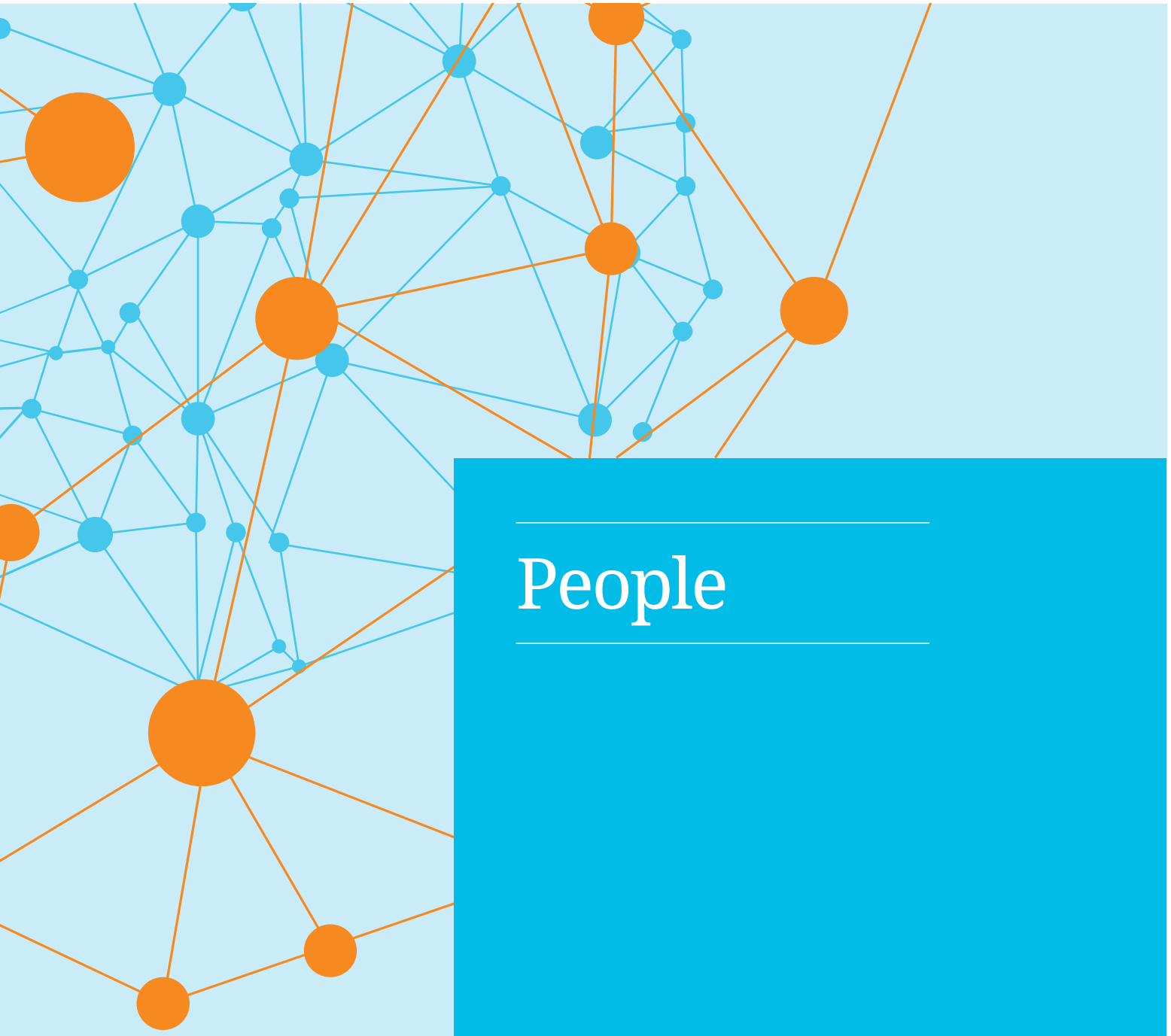
The relatively small scale of New Zealand's science system means it is generally unrealistic to wholly fund and locate very large-scale infrastructure here. International co-funding arrangements for larger-scale equipment are becoming increasingly important globally. The multi-user nature and high capital cost of infrastructure makes it suitable for such funding arrangements. New Zealand researchers gain access to the Australian Synchrotron and Square Kilometre Array in this way.

In spite of this, OECD data suggest that New Zealand directs a similar proportion of its research expenditure to capital items as other countries.

Figure 40 Proportion of capital and current expenditure on R&D (latest available year)







People

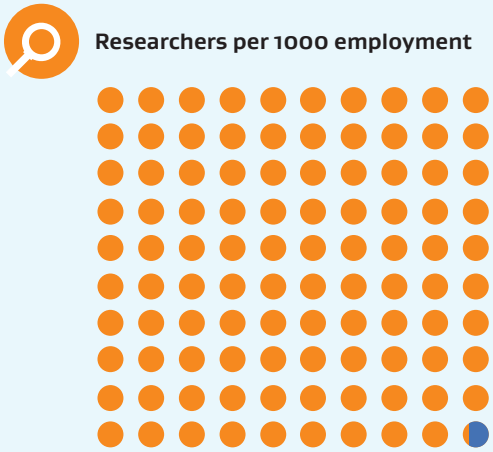
People

Researchers are at the core of the research, science and innovation system. They supply the skills, knowledge, creativity, connections and human resource to apply, create and communicate knowledge. This section presents basic data on who New Zealand's researchers are and where they work.

The 'skills pipeline' section (yellow in this report) shows the flow of people into research through the education sector and migration.

The Research, Science and Technology Domain plan will enable future analysis on how researchers move and transfer knowledge around the system over the course of their careers.

Nearly 8 in every 1000 workers are employed as researchers



RESEARCH WORKFORCE

Number of researchers

The number of researchers in New Zealand has increased by 40% to 31,000 between 2006 and 2016. This includes researchers and PhD students (research Masters students are excluded for OECD comparability).

Figure 41 Number of Researchers (Headcount)

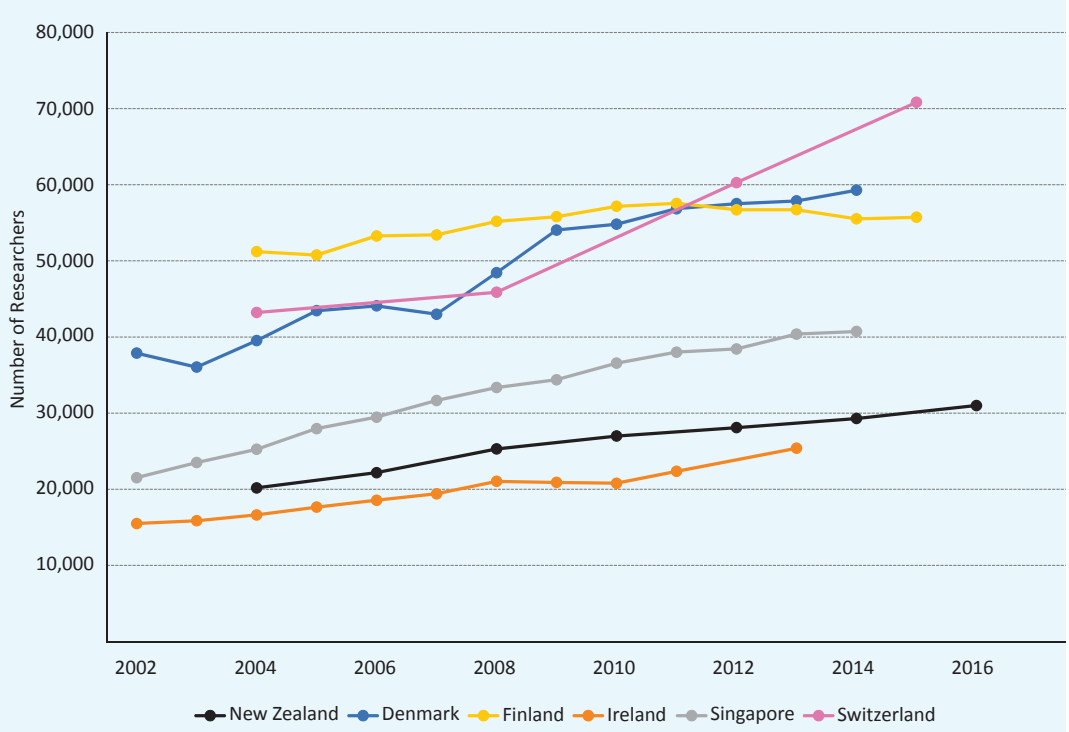
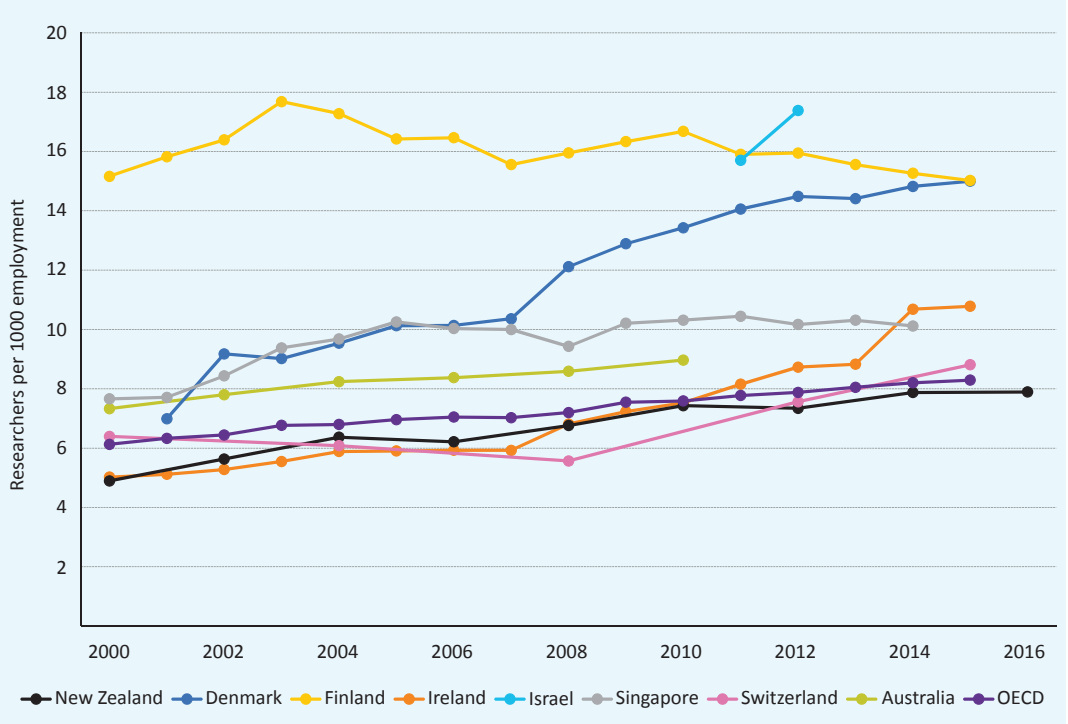


Figure 42 Researchers per 1000 employment

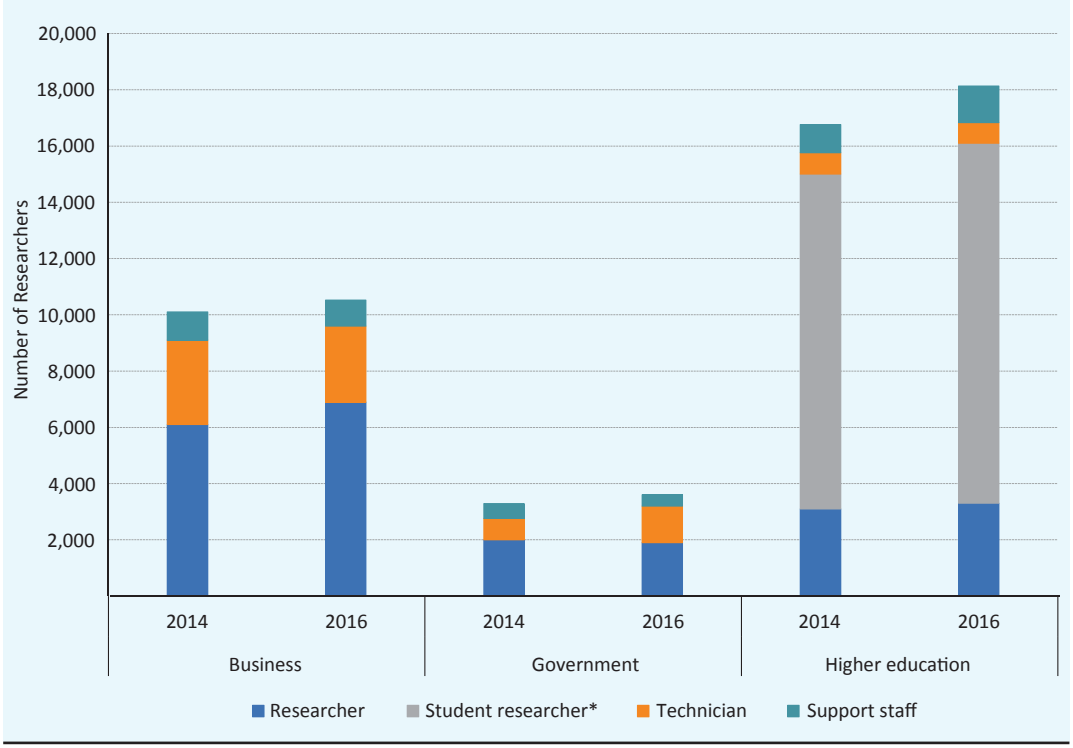


Researchers per 1,000 employment indicate the proportion of the working population engaged in R&D. New Zealand's relatively low score compared with other Small Advanced Economies is consistent with the small size of our science and innovation system relative to the rest of the economy.

Split of researchers by sector (Government, higher education, business)

This shows where researchers work, reflecting the amount of research conducted in the different sectors.

Figure 43 Researchers by sector (Full-time equivalents)



The highest number of researchers (by FTE) are in higher education, but the majority of these are students conducting research as part of their studies. Excluding these, shows that the private sector is the largest employer of researchers.

Total researcher FTEs grew from 17,900 to 18,700 between 2014 to 2016, driven by more researchers in business and student researchers in higher education. This is indicative of increasing business R&D, and an increase in the size of the tertiary sector research skills pipeline.

* Excludes Master students doing research.

RESEARCHER DEMOGRAPHICS

The gender and ethnic split of researchers indicates the equality of opportunities to participate in the research system, and how well diverse perspectives are incorporated.

Data in this area is incomplete and not consistently collected. The Research, Science and Technology Domain Plan will improve this situation by systematically aggregating science fund administration datasets.

The data we have is limited to male and female and do not include other gender identities.

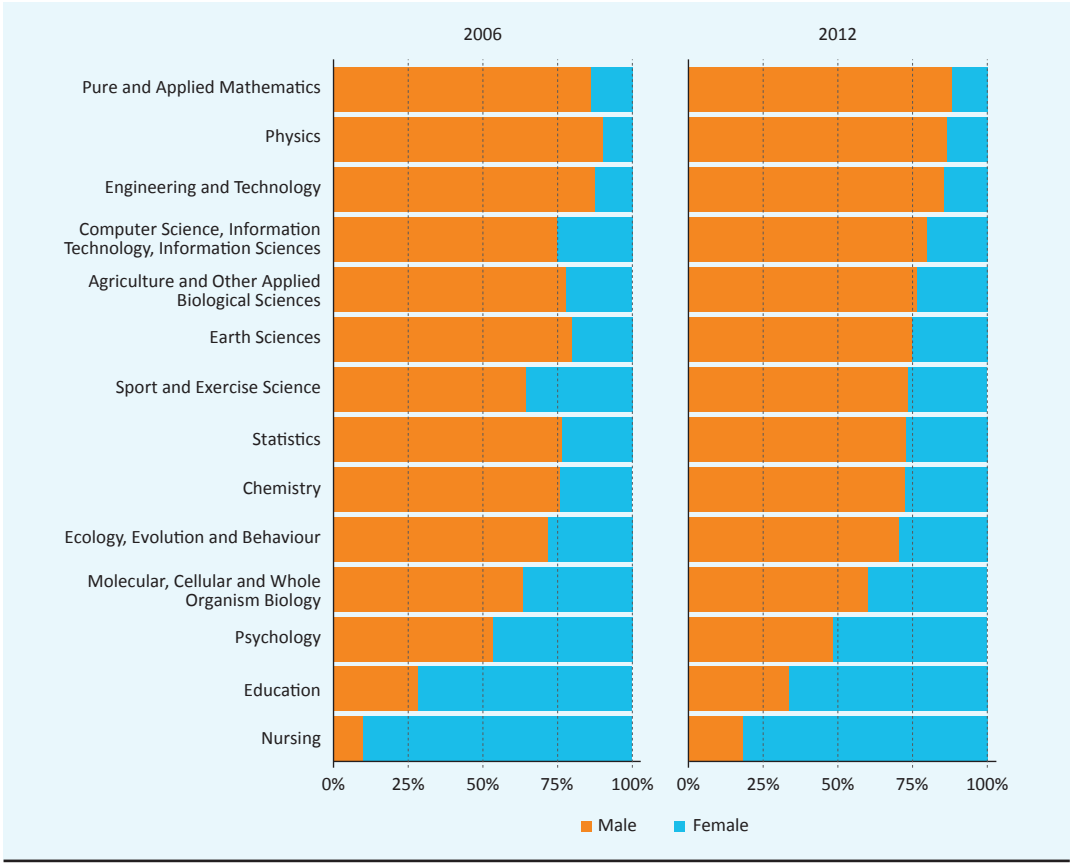
Gender split of researchers

This shows the gender split of researchers in each field in the tertiary sector. The latest data available in this area is from the 2012 Performance Based Research Fund Quality Evaluation.

It may reflect where research fields have higher barriers to entry for one gender, as well as gender-specific preferences for particular fields.

Male-dominated fields appear at the top of the chart and female-dominated fields at the bottom. Some gender-unbalanced fields have become slightly more gender balanced between 2006 and 2012 (Physics, Earth Sciences and Nursing) whilst others now have moved the other way (IT and mathematics).

Figure 44 Proportion of male and female researchers by field in the tertiary sector, 2006 and 2012



Gender split of doctoral students

The gender split of doctoral degree graduates is one factor likely to influence the gender mix of the future researcher population. This will also be influenced by the fraction of each gender going on to be researchers, their progression in the workforce, and the gender mix coming to and leaving New Zealand.

There were more female than male doctoral degree graduates in 2016. This was driven by their dominance in the fields of Health, Education, and Society and Culture. Male researchers dominate sectors such as Engineering and IT, while the Natural and Physical Sciences had an equal split of men and women.

A consistent trend is seen since 2008 of more female than male doctoral graduates.

Figure 45 Domestic students completing doctoral degrees by gender in 2016

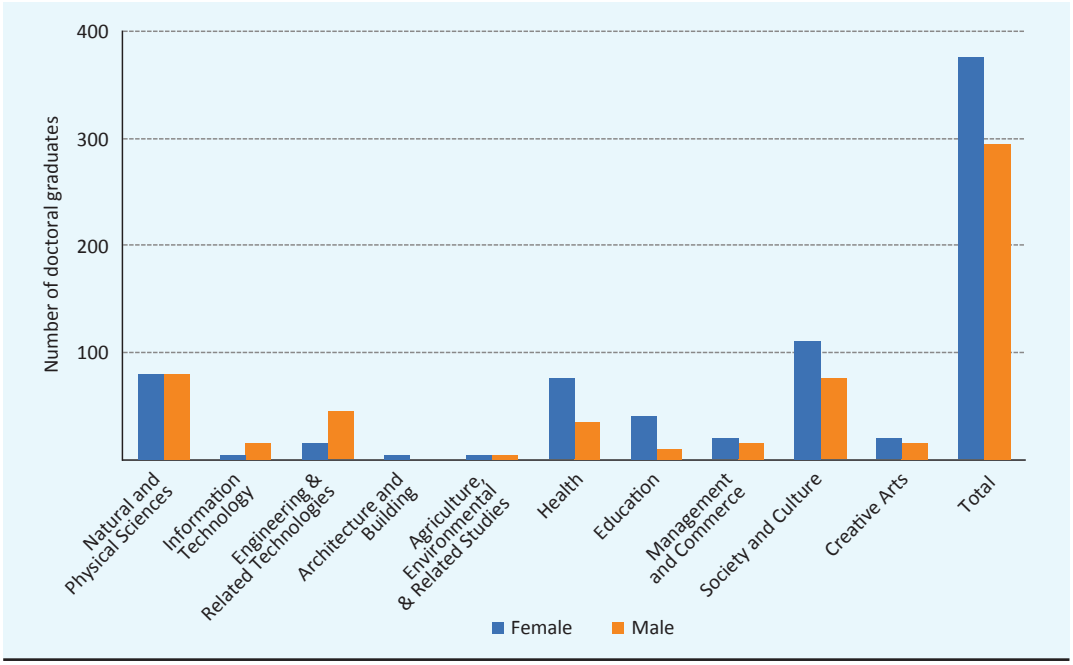
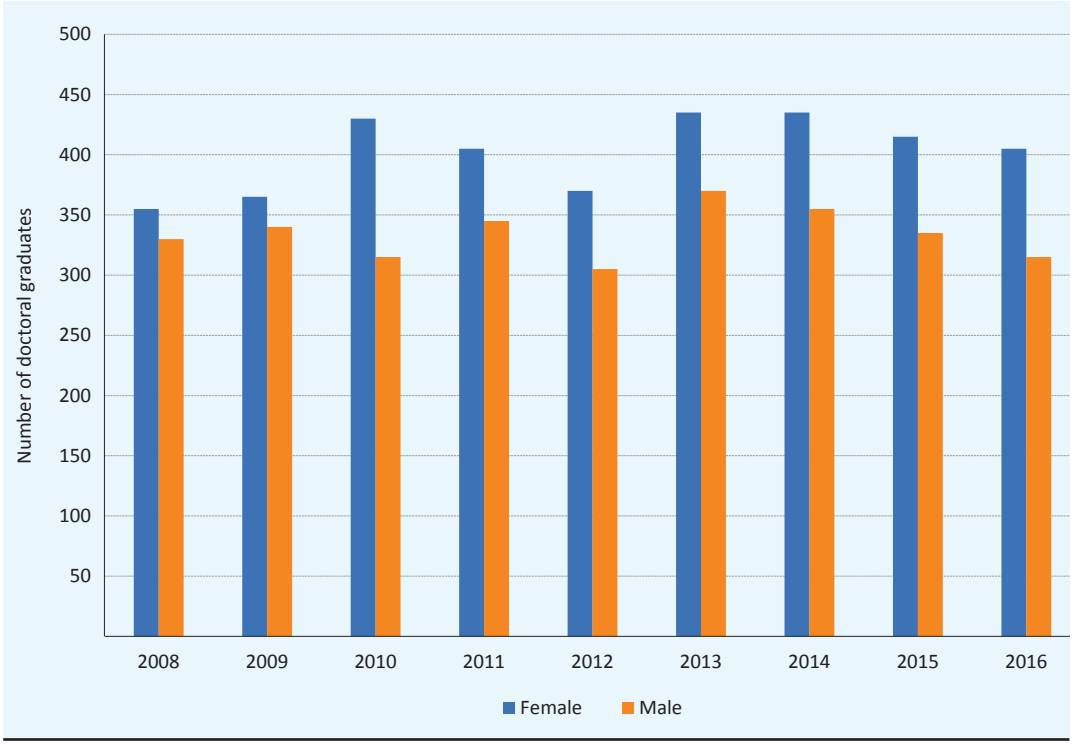


Figure 46 Domestic students completing doctoral degrees by gender, 2008–2016

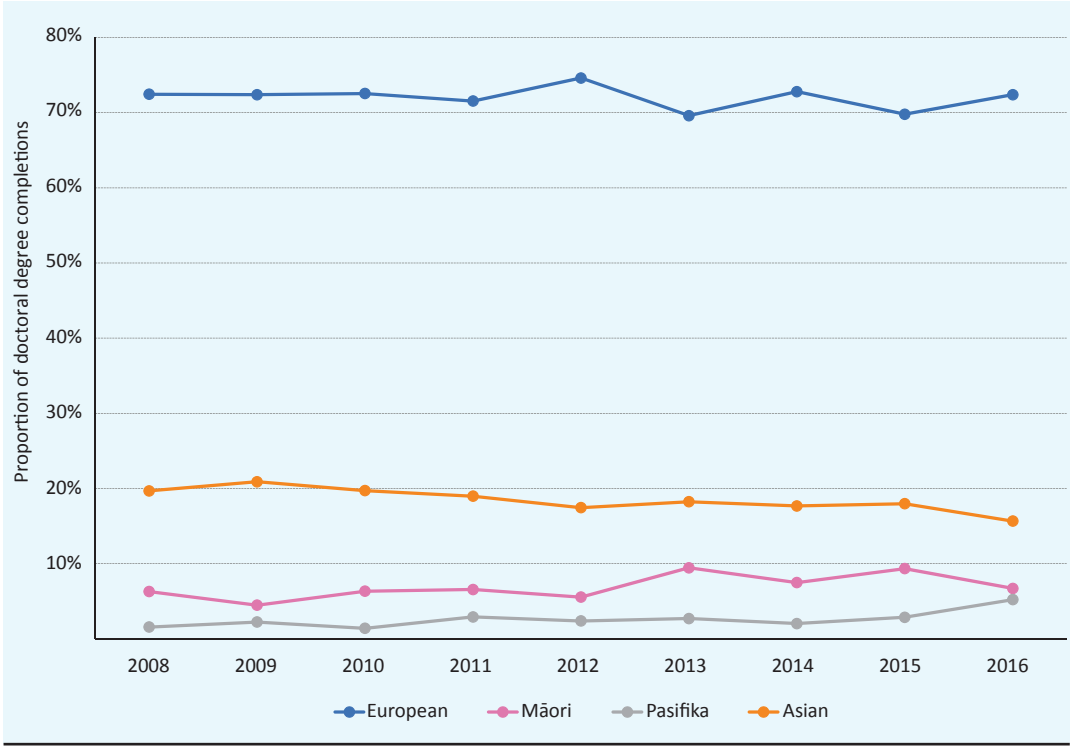


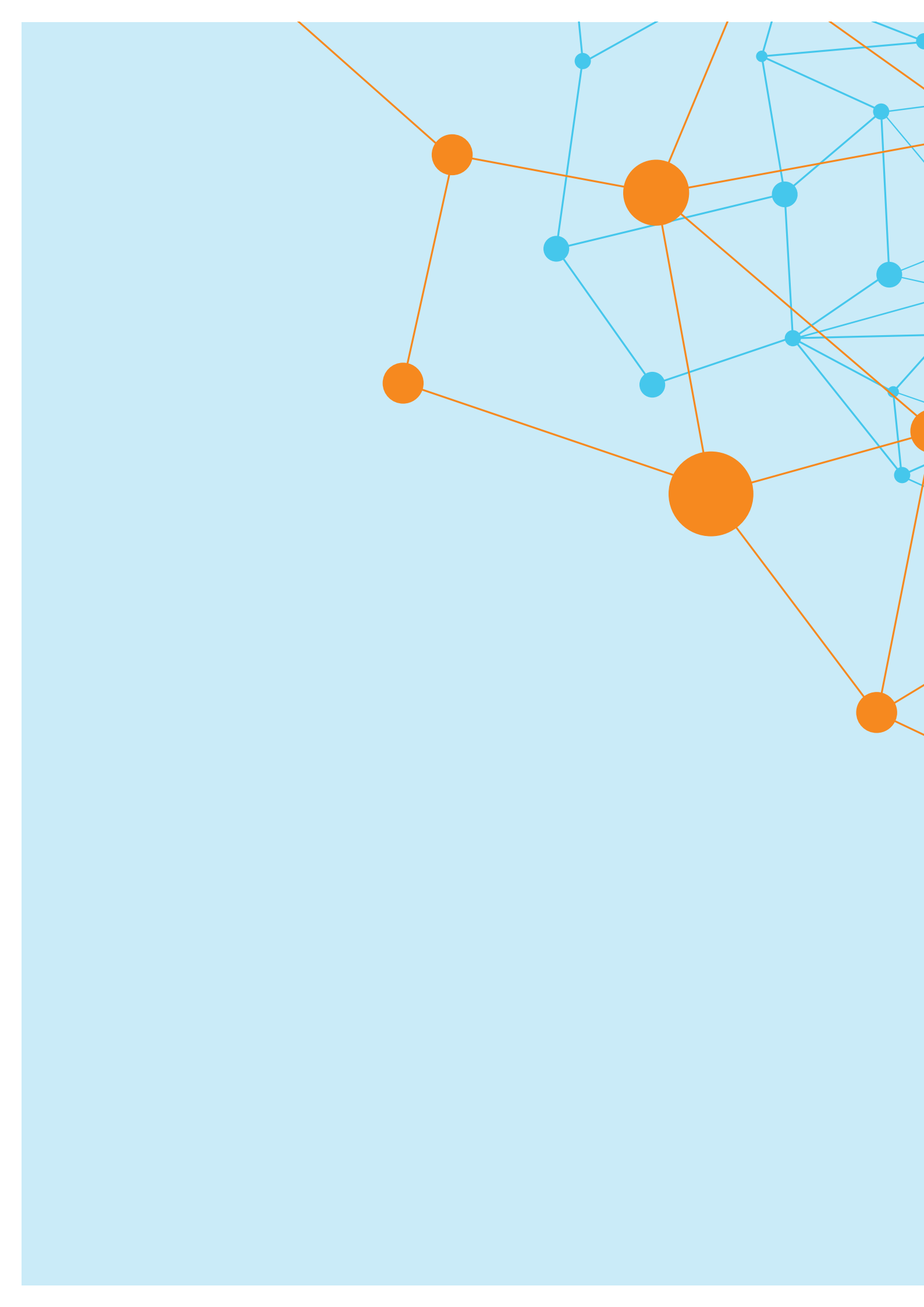
Ethnic background of researchers

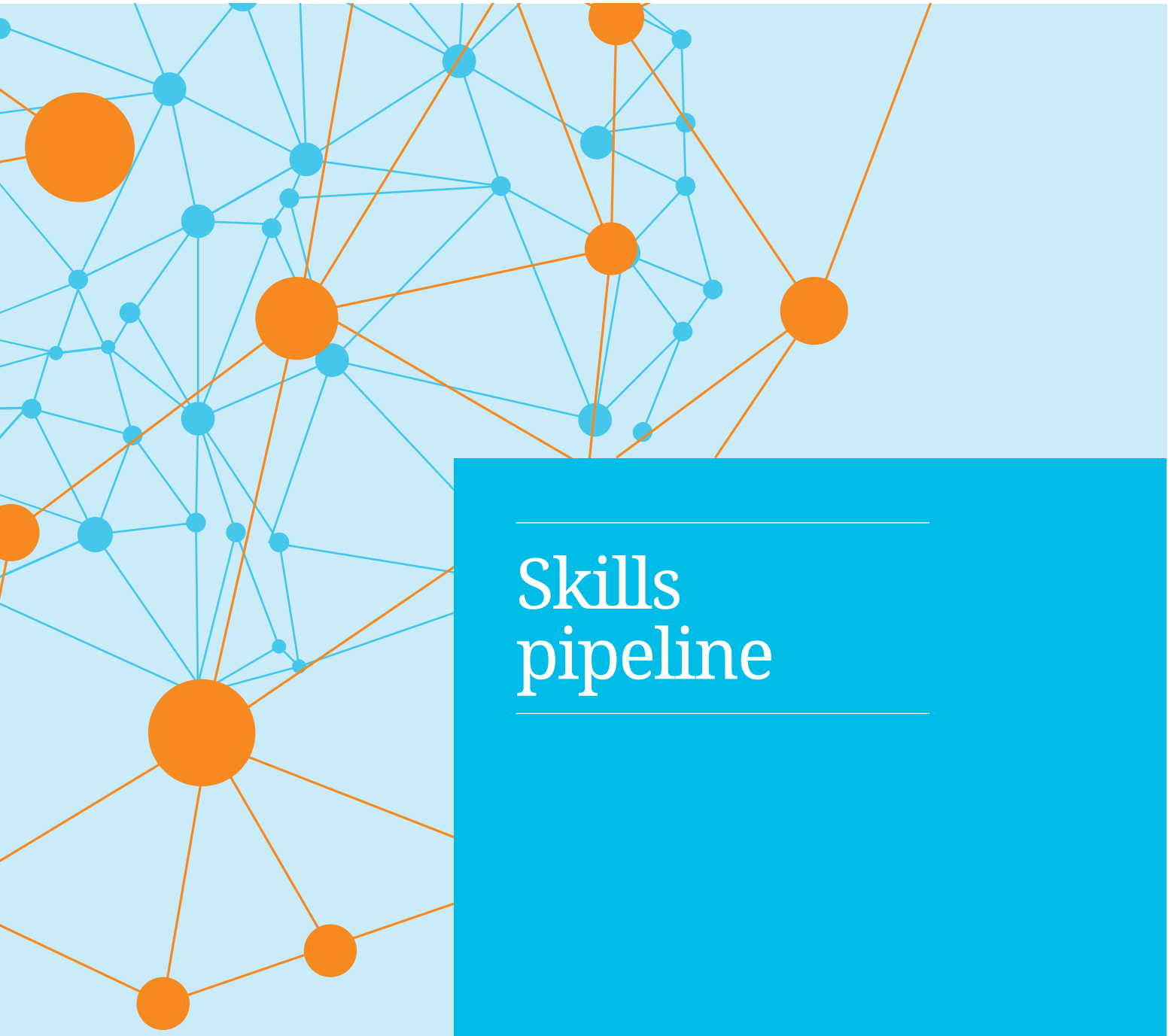
The 2008 survey of scientists and technologists is the most recent and most complete data source in this area. The results indicated that, compared with the general population (15-64 year olds in 2013), Europeans are over-represented among researchers (81 per cent of researchers vs 73 per cent of general population). Asians are under-represented (4.4 per cent vs 14 per cent), as are Māori (1.7 per cent vs 15 per cent) and Pacific Peoples (0.6 per cent vs 7 per cent).

Doctoral degree completion data for domestic students is an indicator of the direction of change for ethnic mix in the researcher workforce. 2016 data shows that 73 per cent of students completing doctoral degrees identified as Europeans, 16 per cent as Asians, 7 per cent as Māori and 4 per cent as Pasifika. These ratios are closer to the general population than 2008 researcher population numbers, but Māori are still particularly under-represented. Figure 47 shows there is no clear trend in these ratios over time.

Figure 47 Doctoral degree completions by ethnic background







Skills pipeline

Skills pipeline

Research, science and innovation cannot happen without appropriately-skilled people. These people may be conducting research or creating innovations in the private or public sector. Their skills may be developed in the school and tertiary education system or brought in by migrants to New Zealand.

There is no one mix of skills that contributes to good innovation performance in all circumstances. Technological innovation involves skills such as pure science and engineering, while organisational innovation involves skills such as problem-solving, team working and communication.

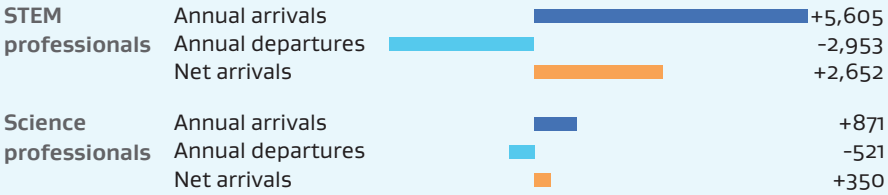
The OECD report on "Skills for Innovation and Research" (2008) suggests that a good supply of highly-skilled people is needed to keep pace with the demands of knowledge-based economic activity and maintain levels of innovation. It identifies management and leadership skills as being of particular importance for all types of innovation.

New Zealand currently faces shortages of highly-skilled engineers, scientists, ICT professionals, university lecturers and post-doctoral fellows, according to the Immigration New Zealand long-term and immediate shortage skills list.

This section focuses on the contribution of New Zealand's STEM skills by looking at the performance, number of students and migration. As described above, a range of other skills are also important for innovation, but they are not reported on here.

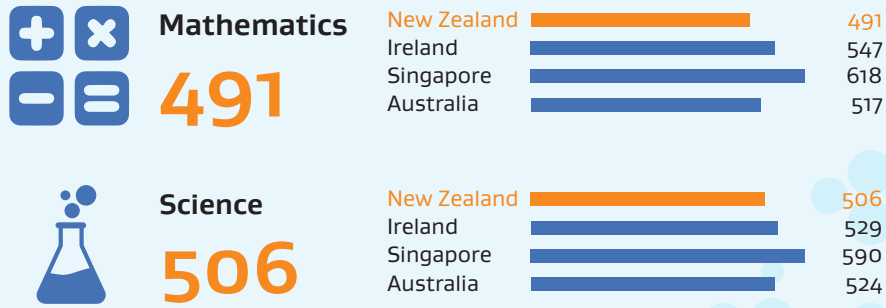
We have a net 'brain-gain' each year

Permanent/long-term migration of Science, Technology, Engineering and Mathematics professionals in 2016



New Zealand students underperform at Science and Maths versus other Small Advanced Economies and Australia

Trends in International Mathematics and Science Study Scores (Year 5, 2015). 500 is the international benchmark.



New Zealand produces relatively few 'STEM' graduates

Proportion of graduates in Science, Technology, Engineering and Mathematics subjects (2016 or 2015)

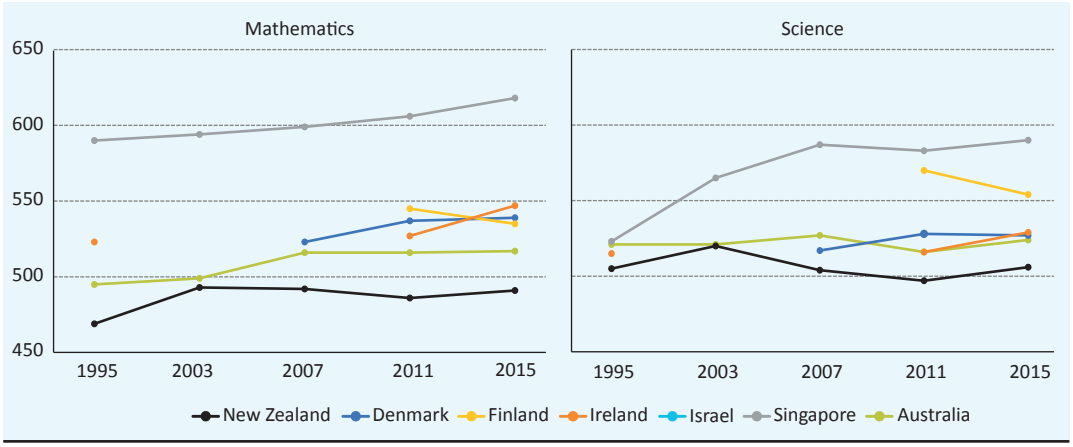
Trends in International Mathematics and Science Study (TIMSS) scores for year 5 and 9

Science and mathematics skills during early education are key foundational skills for further technical and academic learning. This is part of providing businesses with the highly-skilled labour force necessary for research and innovation. Recent UK evidence indicates that skills in mathematics directly correlate with increased incomes[12] – a reflection of the value of these skills to employers and employees.

The Trends in International Mathematics and Science Study (TIMSS) provides regular international comparative assessments of student achievement in mathematics and science. TIMSS provides information on middle primary (year five in New Zealand) and early secondary students (year nine in New Zealand). It gathers information during the course of schooling.

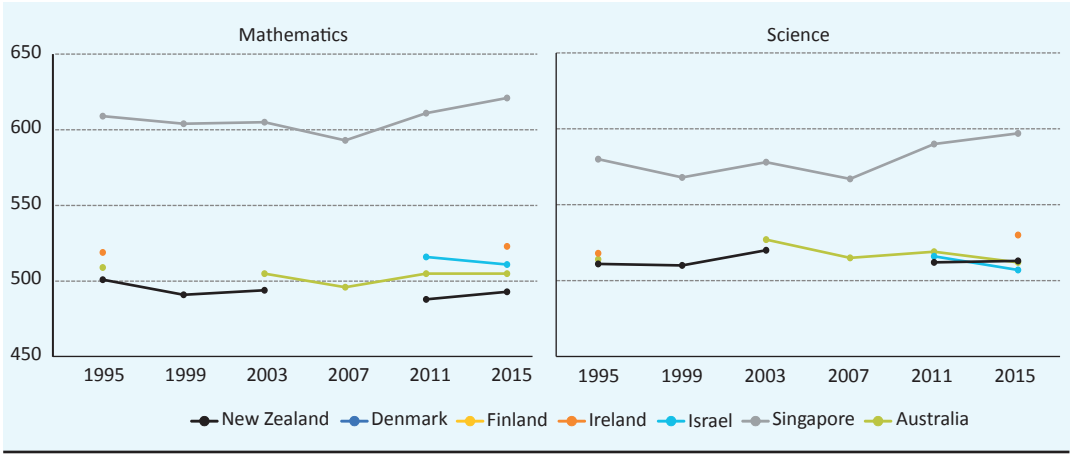
The scale is set so that 500 was the international average† in 1995, and 100 points corresponds to one standard deviation.

Figure 48 Year Five* scores on Trends in International Mathematics and Science Study



At Year Five, New Zealand primary school children score around or below the 1995 international average (500 points) for Mathematics and Science, and significantly below other Small Advanced Economies and Australia. This result is consistent since 2007.

Figure 49 Year Nine* scores on Trends in International Mathematics and Science Study



At Year Nine, the pattern is similar to Year Five, although New Zealand is rather closer to the scores of other Small Advanced Economies.

* or grade equivalent for countries other than New Zealand

† 45 countries participated in 1995, of which two-thirds were OECD countries.

School leavers' attainment in mathematics and science

The proportion of school leavers attaining maths, science or engineering and manufacturing NCEA qualifications is steadily increasing.

This measure shows the proportion of school leavers who attained at least 14 credits in a learning area at Level 1, 2 or 3 of the New Zealand Qualifications Framework. The school leavers have attained at least 14 credits from standards assessed at the stated level (or a higher level) with a result of Achieved, Merit or Excellence. The two learning areas reported here are Mathematics and Statistics, and Sciences.

For Mathematics and Statistics the proportion of school leavers attaining Level 2 and 3 increased steadily since 2009, however a slight decline is evident in 2016. The proportion of school leavers attaining Level 1 has decreased since 2012 for mathematics. A key factor behind this is the expiry of low-level unit standards in mathematics from 2011. For Sciences, there has been a small but steady increase in the proportion of school leavers attaining Levels 1 and 2 since 2009.

The proportion of students attaining Level 3 in engineering and manufacturing has roughly tripled from 2 per cent to 6 per cent since 2009.

Figure 50 Proportion of School Leavers achieving at least 14 credits in Mathematics and Sciences at Levels 1-3

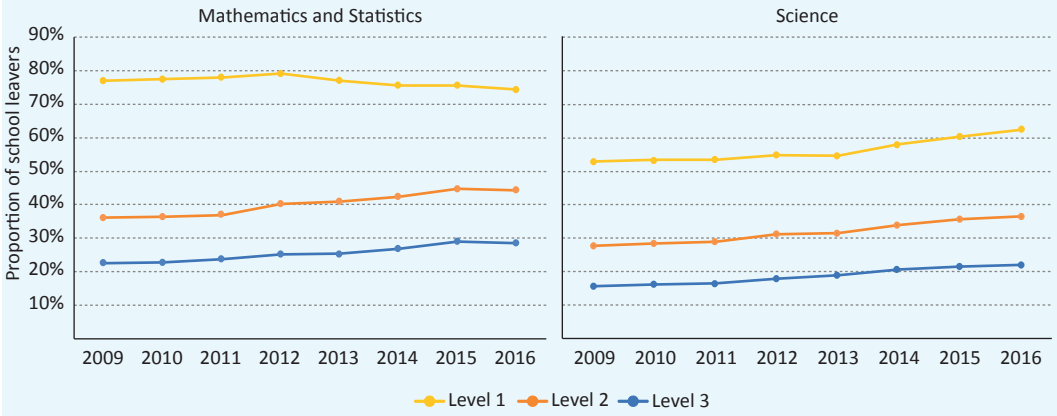
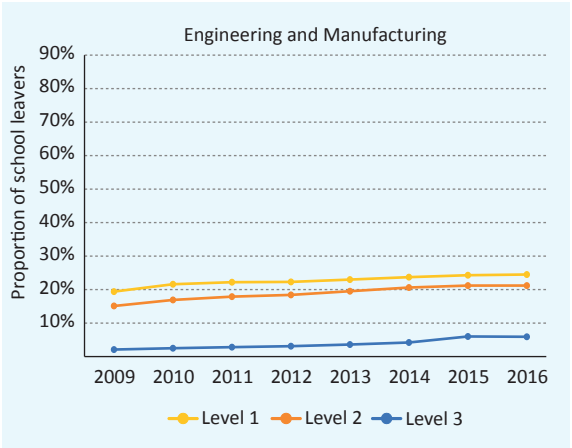


Figure 50a Proportion of School Leavers achieving at least 14 credits in Engineering and Manufacturing at Levels 1-3



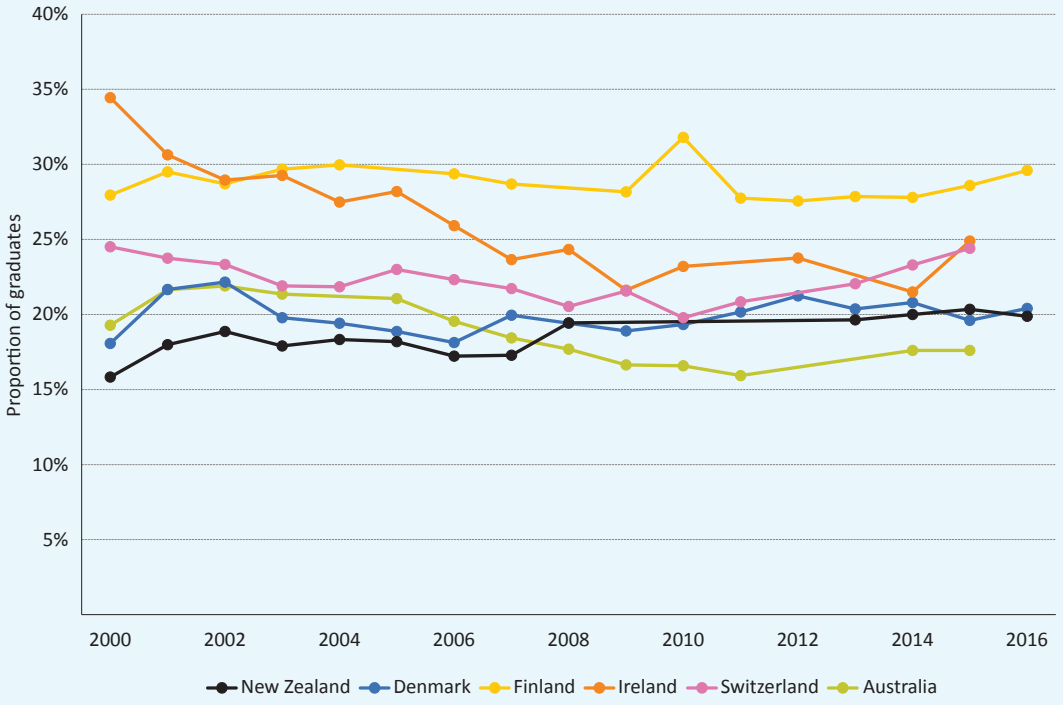
Graduates in STEM subjects per annum

This measures the number and proportion of students who graduate with qualifications in STEM subjects each year (Science, Technology, Engineering and Mathematics).

To successfully innovate, businesses need access to a broad range of highly-skilled labour. In addition to critical thinking, broader academic and technical training, technological innovation is supported by strong foundational and advanced STEM skills.

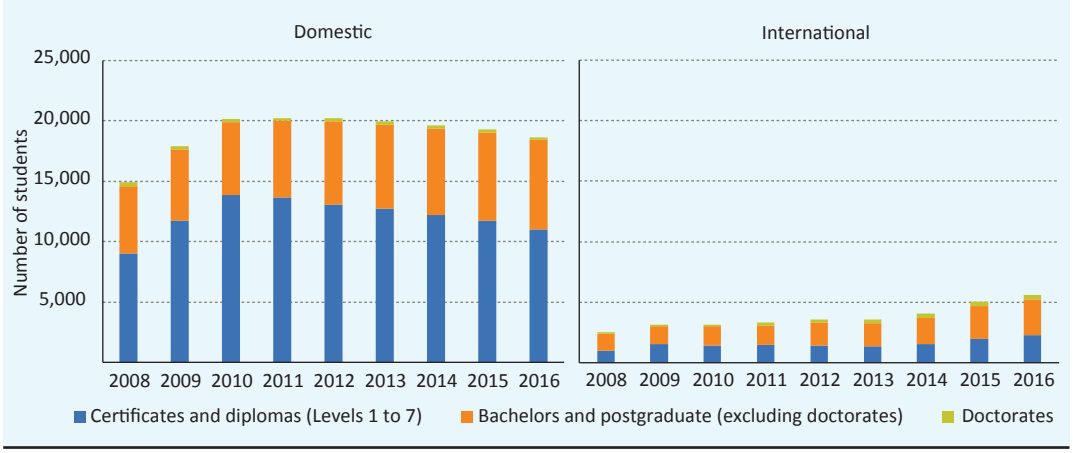
The proportion of tertiary students graduating in STEM subjects has remained broadly constant since 2000. New Zealand's STEM graduate share remains low compared to other Small Advanced Economies.

Figure 51 Proportion of graduates who are in STEM subjects

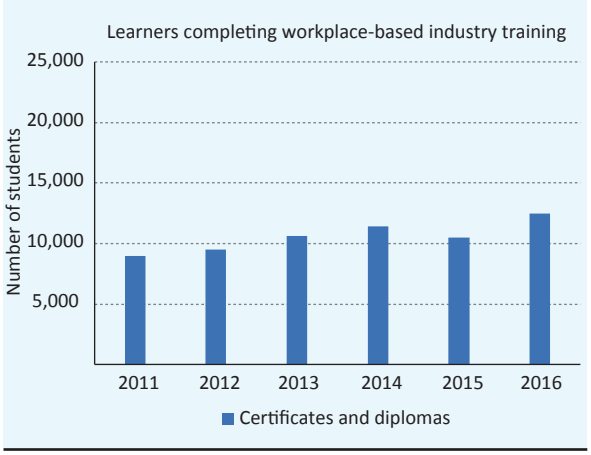


At the absolute level, fewer domestic students are attaining STEM certificates and diplomas, but this has been somewhat offset by increases in domestic degree level qualifications. The number of workplace based industry-training certificates has steadily increased, as has the number of international students gaining degrees and higher level qualifications.

Figure 52 People completing qualifications in STEM fields*



* Note that totals may slightly overstate student numbers, because some people complete more than one level in a year. See the supporting data tables for the total figure adjusted to remove this double-counting.

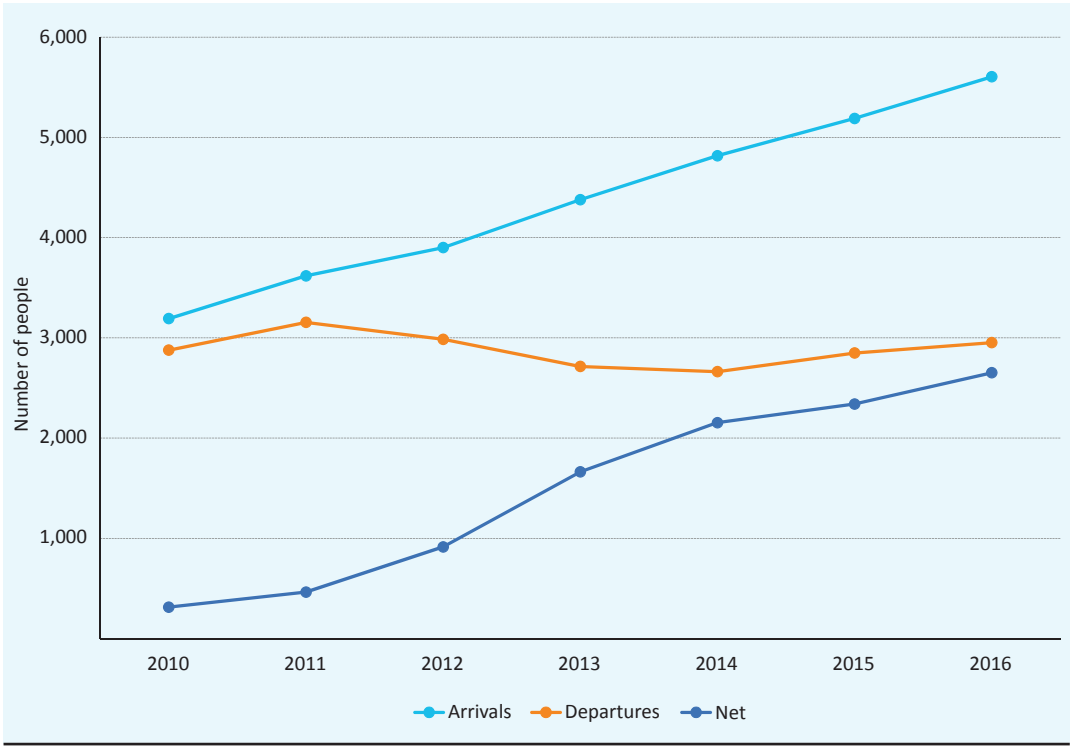


Inward migration of scientists and STEM professionals

This indicator shows the number of permanent and long-term arrivals/departures (for more than 12 months) of people in a science, engineering or IT-related occupation.

This shows whether New Zealand has a net 'brain-gain' or 'brain-drain'. Migrants are an important source of skills for New Zealand's research, science and innovation system.

Figure 53 Inward migration of STEM professionals

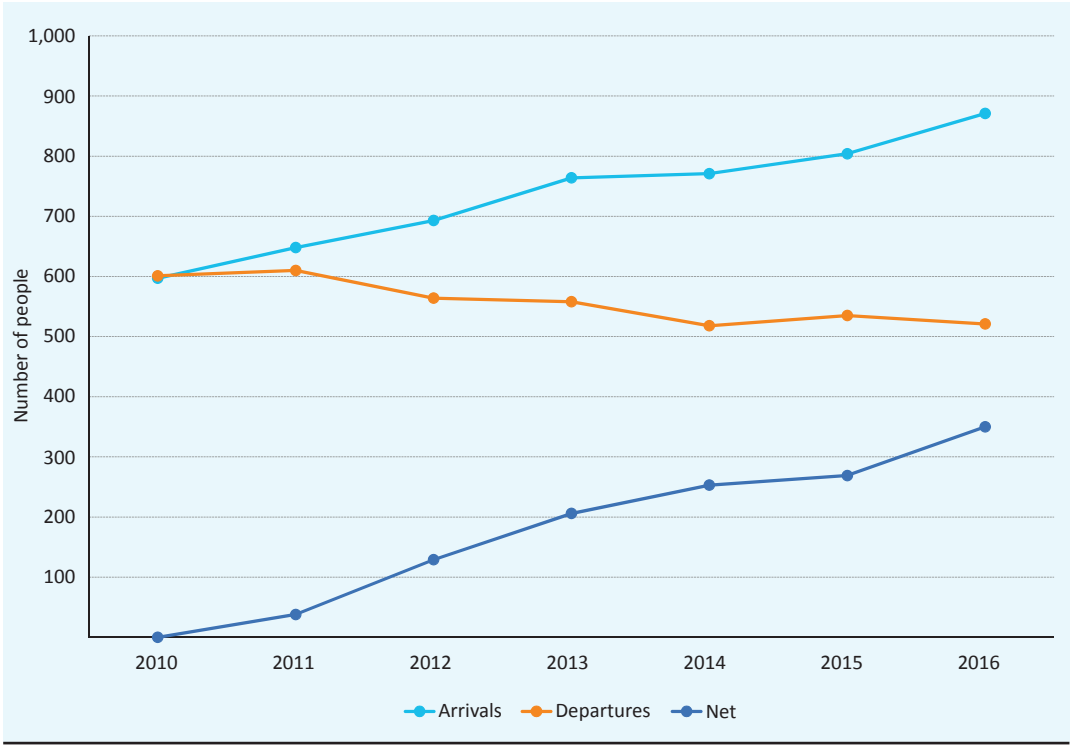


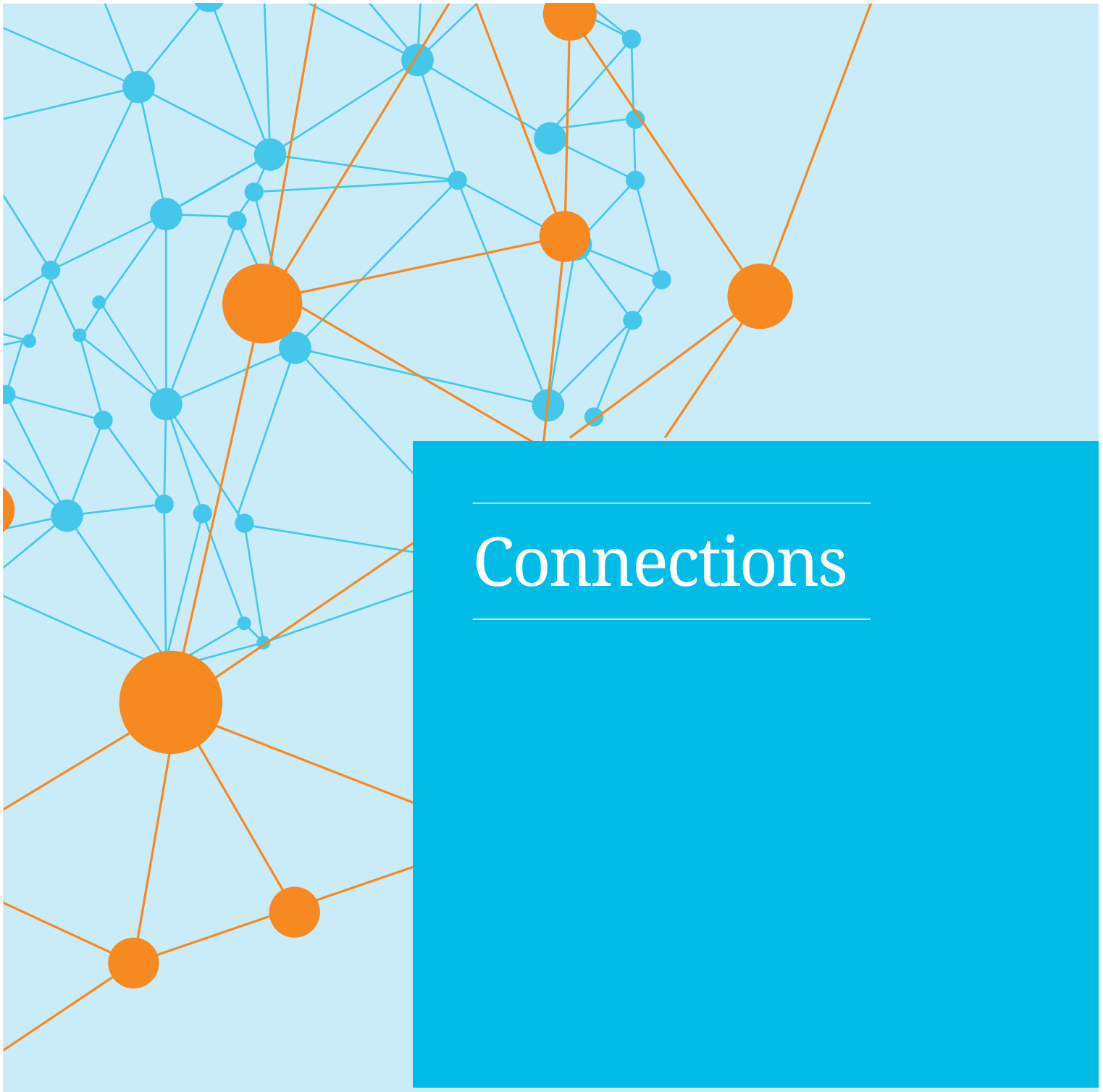
Figures 53 and 54 show that New Zealand has had a net, and growing, 'brain-gain' of both scientists and STEM professionals* overall since 2010. A steady number depart each year, but a greater number arrive, and this is steadily growing year-on-year.

About 50 per cent of STEM arrivals are engineers, with about 33 per cent in IT-related occupations and 17 per cent in Natural science professions. The pattern of flat annual departures and steadily rising arrivals has been broadly mirrored across engineering, IT and science.

* This category includes Engineering Professionals; Natural and Physical Science Professionals; Business and Systems Analysts, and Programmers; Database and Systems Administrators and ICT Security Specialists; and ICT Network and Support Professionals.

Figure 54 Inward migration of Science professionals





Connections

Connections

The free flow of knowledge and ideas is fundamental to the research, science and innovation system. It can occur through traditional research outputs but also through collaboration and social interaction of all forms. Sharing ideas broadly across disciplines stimulates scientific progress and makes impacts more likely. Connecting with research, science and innovation in the rest of the world keeps New Zealand abreast of the global knowledge and technology frontier.

NZ has high international collaboration rates

Proportion of publications with international co-authorship

NZ 54%

OECD 29%

Academic-business collaboration remains low

Academic-business-co-authorship

NZ 1.5%

OECD 2.3%

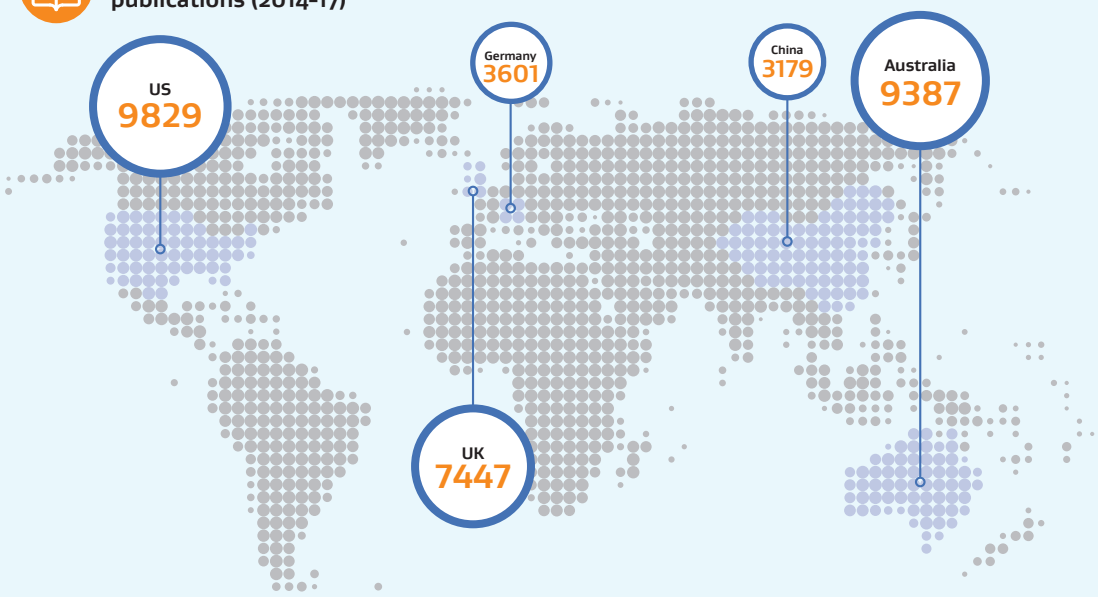
University research funded by business

NZ 4.6%

OECD 6.2%

Top collaborator countries

Number of co-authored publications (2014-17)



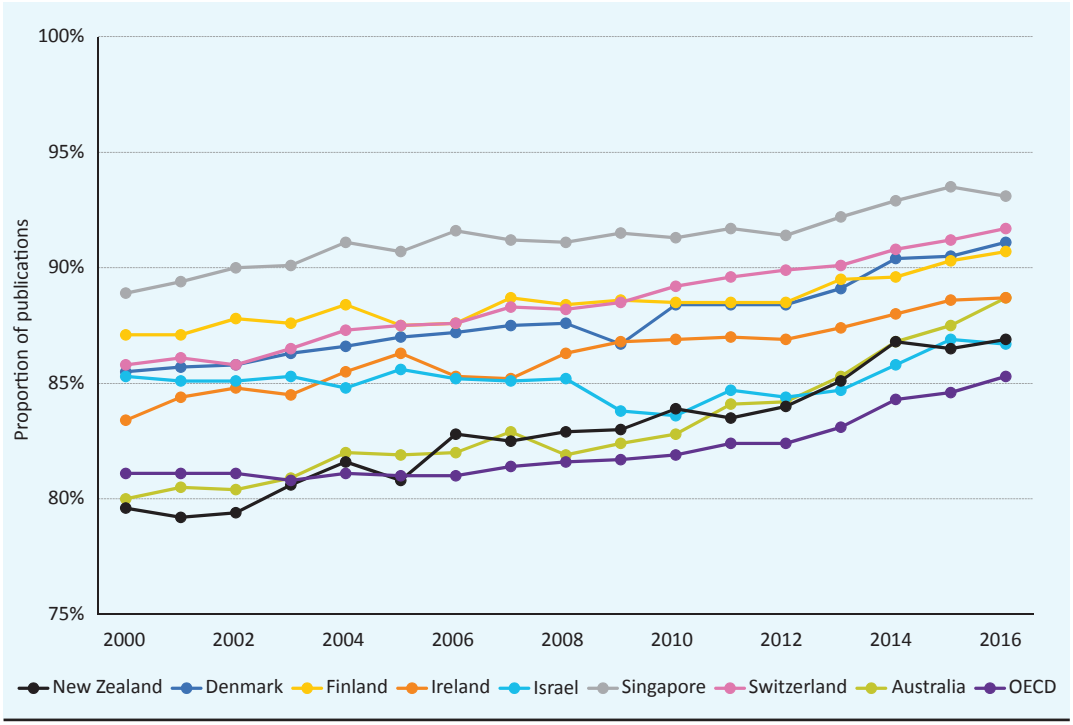
PROPORTION OF SCHOLARLY OUTPUT WITH COLLABORATION

This indicator shows what proportion of scholarly output has more than one author, showing how much researchers are collaborating.

A number of studies have shown that collaboration between researchers is associated with greater citation impact[17,18]. The dramatic growth in the breadth and depth of scientific knowledge over the last century has the capacity of any single researcher to comprehend enough existing knowledge to make scientific progress in isolation.

Figure 55 shows that collaboration rates are rising across the OECD and Small Advanced Economies. New Zealand does marginally better than the OECD average on this indicator. We have a similar rate of collaboration papers to Israel but we do not do as well as the other Small Advanced Economies and Australia.

Figure 55 Proportion of publications with more than one author



Focus Box

Domestic collaborations

DOMESTIC COLLABORATION PARTNERS

Figure 56 shows the co-authorship relationships between institutions in different New Zealand research sectors. Thicker lines indicate more co-authored publications. Line colour indicates citation performance (fraction of publications in top 10 per cent worldwide) – blue indicates better citation performance, pink indicates poorer performance. Loops indicate collaborations between different institutions in the same category.

Some of the higher-cited collaborations are between District Health Boards and CRIs, and District Health Boards with the private sector.

Figure 56 Collaborations between different types of New Zealand research organisation (2012–16)

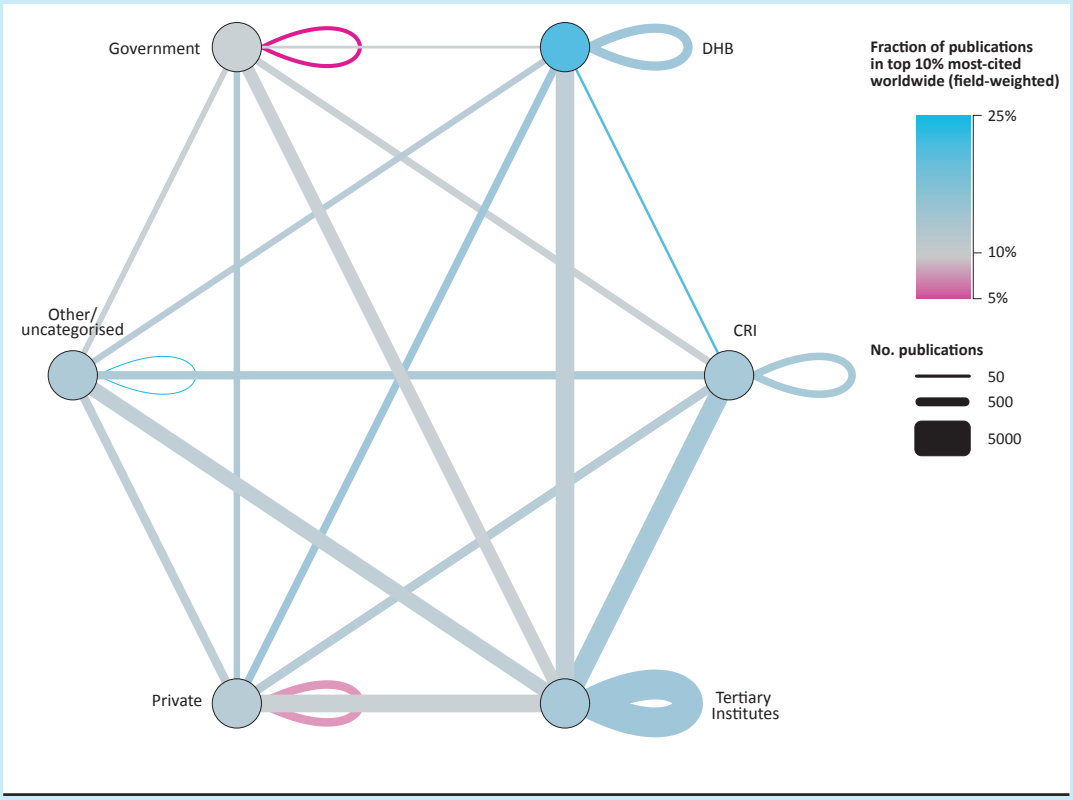
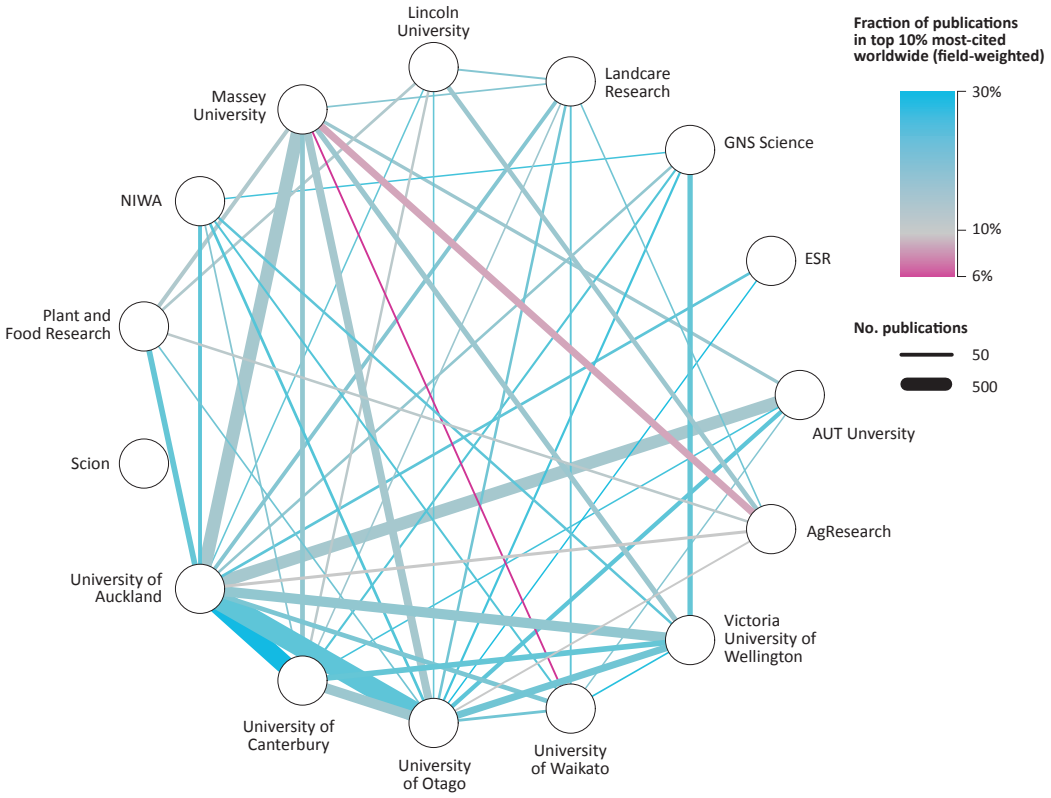


Figure 57 gives more detail on how much different New Zealand institutions are collaborating. Lines are only shown where there are at least 50 co-authored publications.

Figure 57 Number and citation performance of institutional collaborations (2012–16)



The University of Auckland appears as a key collaborator in the system, and has a significant number of highly-cited collaborations with Canterbury. This appears to be partly driven by being part of some mega-authored publications (1000+ authors) in experimental particle physics. Such papers can receive high citation rates, but the number of contributors means it is probably inappropriate to attribute this to a particular institution.

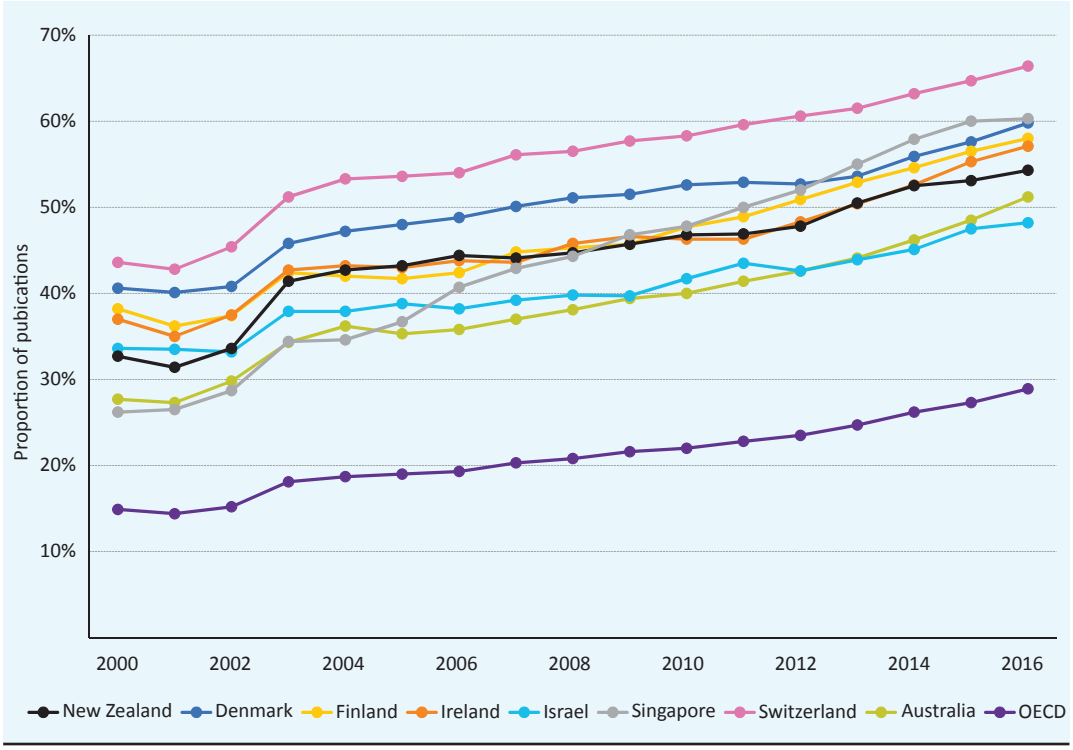
Scion has no collaboration links shown in the diagram, because there were no other New Zealand institutions with which it co-authored 50 or more Scopus papers in the period. Scion publishes less than most other CRIs and has marginally lower domestic collaboration rates on this measure (42 per cent, compared to 51 per cent average for CRIs). This analysis excludes international collaborations, of which Scion has a number, research outputs not appearing in Scopus, and other types of collaboration.

Proportion of scholarly output with international collaboration

This indicator shows the proportion of research output with authors from more than one country. This is a measure of the extent of international collaboration by New Zealand researchers. Research outputs with international collaboration appear in better journals and are more highly-cited than local research on average[18, 19].

World rates of paper co-authorship have increased substantially over time – from around 10 per cent or less at the start of the 20th century.

Figure 58 Proportion of scholarly output with international co-authorship



The proportion of papers with international collaboration is increasing in New Zealand and across the OECD and Small Advanced Economies. New Zealand does considerably better than the OECD average and Australia on this indicator and is on a par with other Small Advanced Economies, with over 50 per cent of papers having international co-authorship. This suggests that New Zealand researchers are relatively well connected to global science.

Our top collaborator countries between 2014 and 2017, in order, are the US (9,829), Australia (9,387), UK (7,447), Germany (3,601), China (3,389) and Canada (3,179) with co-authored publications. Nearly half of our international co-authored papers include these countries.

Figure 59 shows the number and proportion of New Zealand research publications with international co-authorship in key fields. Biochemistry, Genetics and Molecular Biology shows the highest rates, followed by Agricultural ad Biological Science. Figure 60 shows that New Zealand is significantly ahead of the world-average collaboration rates in each of these fields.

Figure 59 Number and proportion of New Zealand publications with international co-authorship by field, 2014–2017

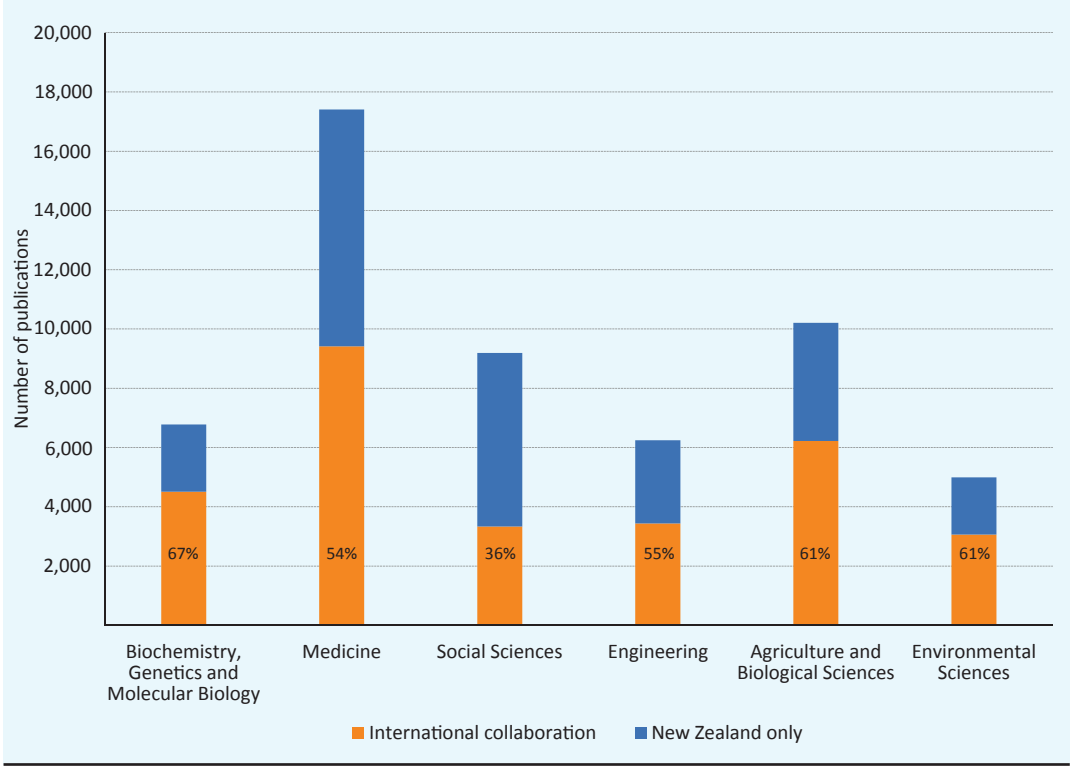
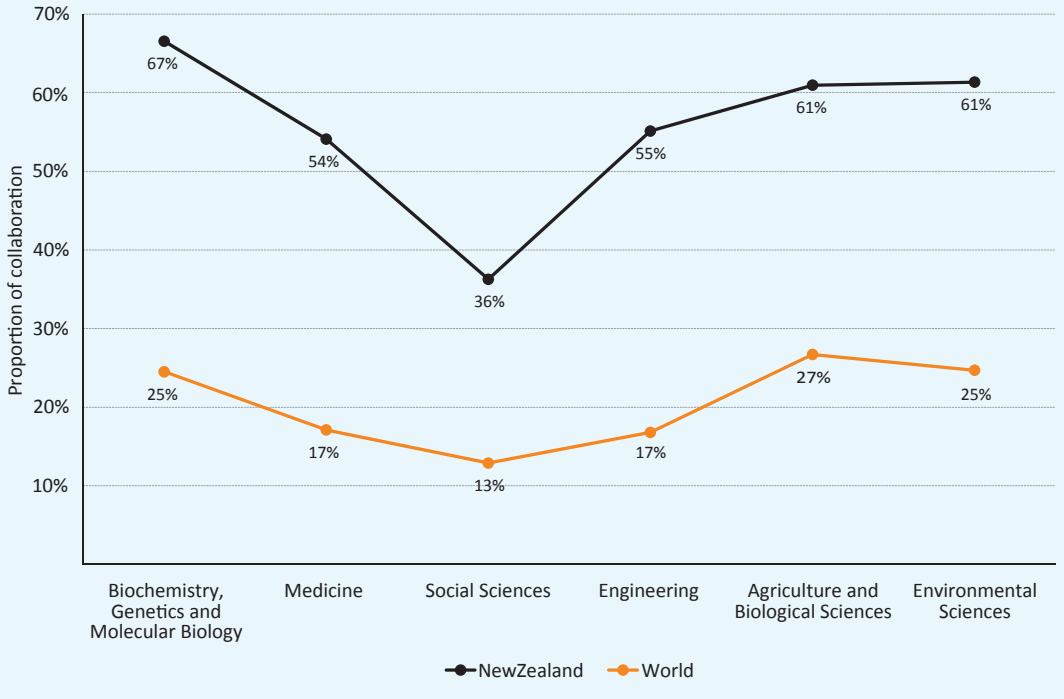


Figure 60 World average of international collaboration rates in certain fields



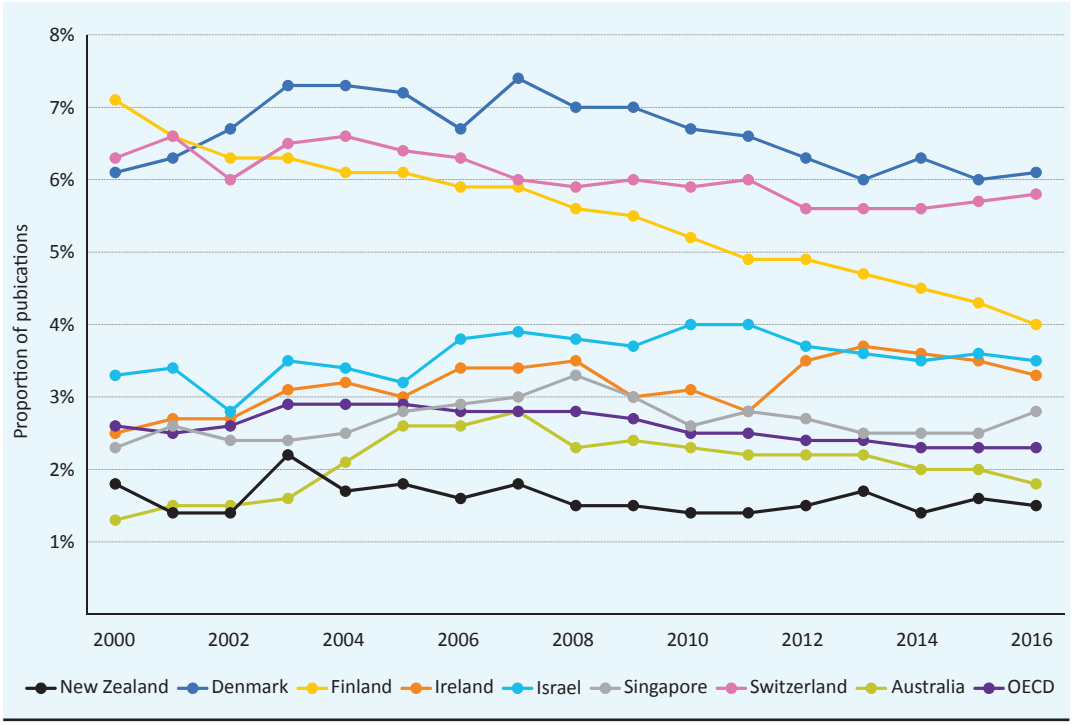
Academic–business collaboration

This shows the proportion of scholarly output which has at least one business-affiliated and one university- or CRI-affiliated author.

This is an indicator of how much private and public institutions are collaborating on research of publishable quality. Such collaboration shows that businesses see value in publicly funded research capability and makes it more likely that publicly funded science will lead to economic benefits.

Practices around including business co-authors in research outputs may vary between firms, institutions and countries. Understanding these practices better will help us understand how accurate this indicator is.

Figure 61 Proportion of publications with academic–business collaboration



Just around 1.5 per cent of New Zealand's scholarly output had academic-business co-authorship in 2016. New Zealand fares poorly on this indicator as compared to other Small Advanced Economies and Australia.

Denmark and Switzerland's rates of academic-business co-authorship are around four times New Zealand's.

Research in universities funded by businesses

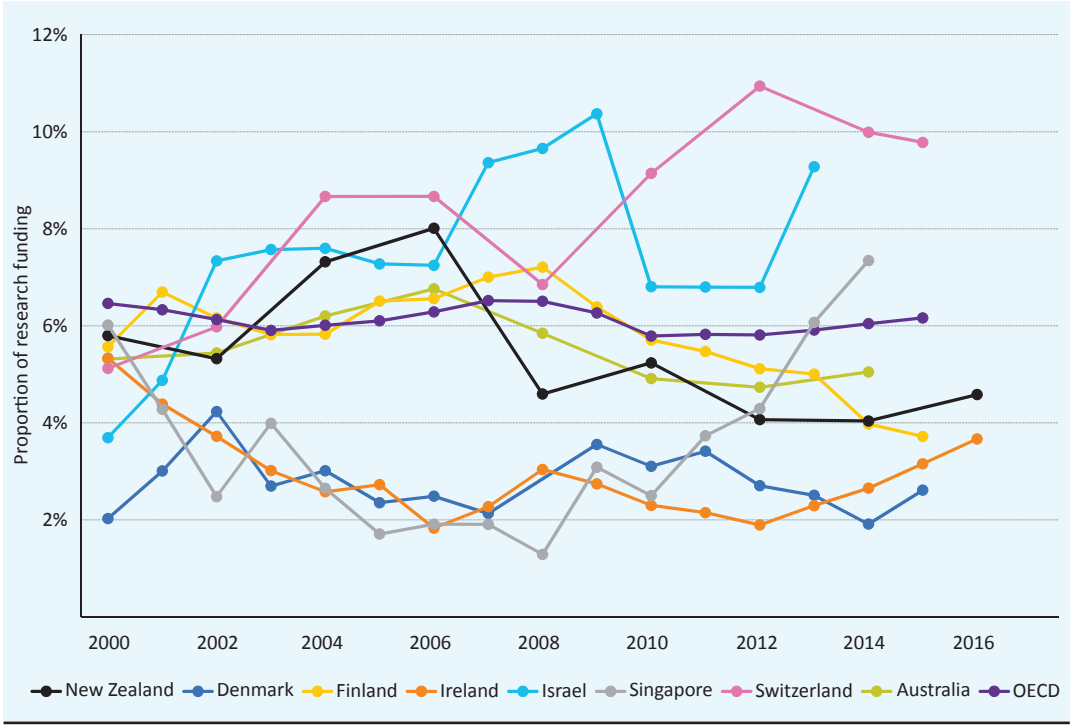
Figure 62 shows the proportion of higher education expenditure on research and development which is funded by industry.

Evidence shows that research in universities that is solely or partly funded by business has substantially higher economic impact, as measured by the proportion of inventions which are patented or licensed[20].

In addition, patents from business-funded work receive higher patent citation rates, indicating greater 'knowledge spillover' effects[21].

This indicator shows research performed within universities, whereas the academic-business collaboration indicator (Figure 61) is likely to include research performed within CRIs, universities and businesses.

Figure 62 Proportion of research in higher education funded by business



Between 4 and 5 per cent of higher education R&D is currently funded by business. This figure is around the middle of the pack when compared to the Small Advanced Economies and Australia.

This indicator has decreased from a high of 7.5 per cent in 2005 to 4.6 in 2016. This decrease is partly a function of increasing public funding, but the dollar value of higher education research funded by business has also decreased by 23 per cent between 2006 and 2014.

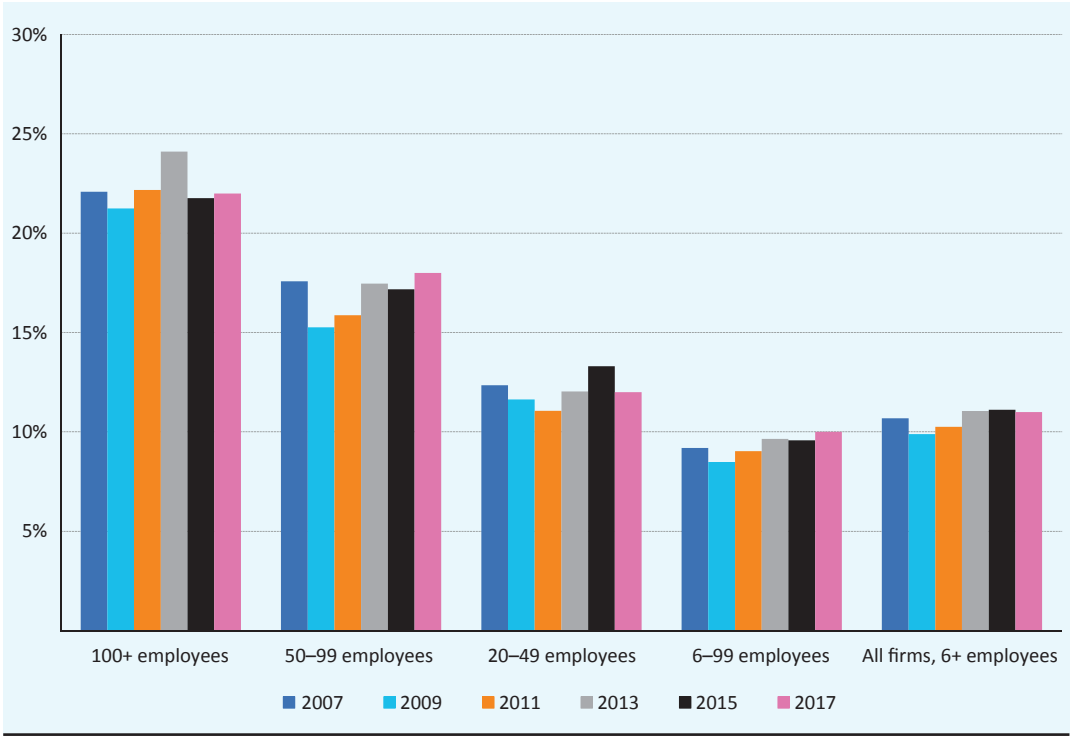
Businesses spend a greater proportion of their R&D funding in the government sector (primarily CRIs) than in the tertiary education sector.

Businesses with cooperative arrangements for the purpose of innovation

This indicator shows the proportion of companies reporting cooperative arrangements with other entities for innovation. This includes cooperation with suppliers, customers and other businesses and also with research organisations.

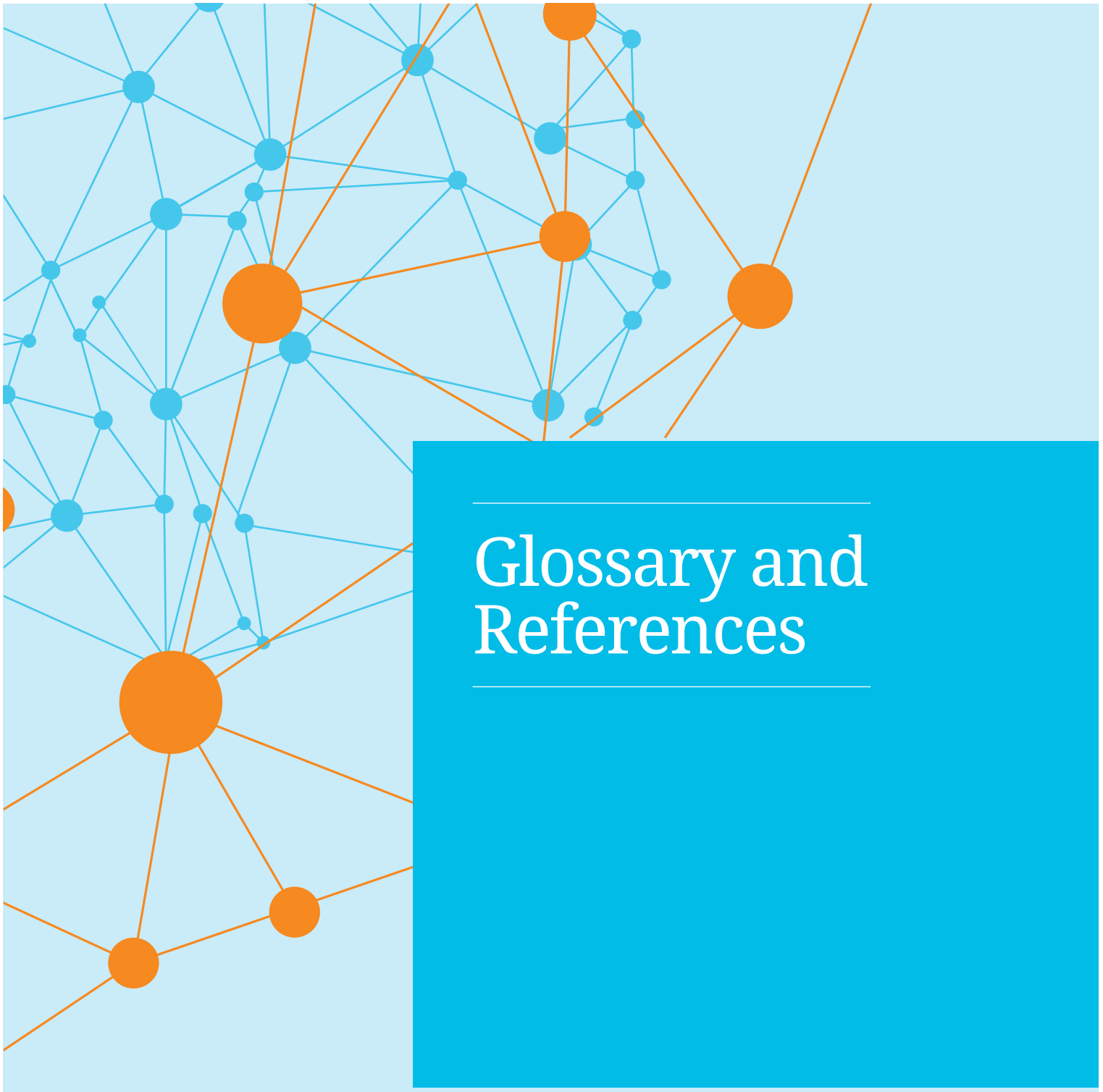
The importance of inter-firm cooperation on research is emphasised by theories such as Open Innovation[22]. This theory recognises that while businesses may naturally resist sharing ideas to protect their intellectual property, there are actually substantial gains to be made from seeking out complementary knowledge and pooling resources and expertise across firms.

Figure 63 Businesses that cooperate on innovation



On average around 10 per cent of New Zealand firms are cooperating on innovation. There appears to be a slight upward trend since 2009.

Large businesses, with greater than 100 employees, are the most likely to cooperate with others on innovation. This mirrors the tendency for larger companies to spend more on R&D.



Glossary and References

Glossary

BERD – Business Expenditure on R&D (i.e. Cost of R&D performed within business, regardless of the source of funding)

Bibliometric measures – Metrics based on the statistical analysis of publications

CRI – Crown Research Institute (there are seven: AgResearch, The Institute of Environmental Science and Research, the National Institute of Water and Atmospheric Research, Landcare Research, Plant and Food Research, GNS Science, and Scion.)

GERD – Gross Expenditure on R&D (i.e. Total expenditure within the country; This is the sum of BERD, HERD and GOVERD)

GOVERD – Government Expenditure on R&D (i.e. Cost of R&D performed within Government, regardless of the source of funding)

HERD – Higher Education Expenditure on R&D (i.e. Cost of R&D performed within Higher Education institutes, regardless of the source of funding)

Impacts – Changes in socio-economic outcomes which are attributable to science and innovation activity

Innovation – The introduction of new or significantly improved goods, services, processes, or marketing methods

MBIE – The Ministry of Business, Innovation and Employment

OECD – Organisation for Economic Co-operation and Development

PPP USD – Purchasing power parity United States Dollars. This converts national currencies to USD using exchange rates which reflect the relative purchasing power of each currency. This reduces the issues associated with rapid fluctuations in market exchange rates

Public Funding of R&D, or **GBAORD** – Government budget appropriations or outlays for research and development (i.e. Cost of R&D with direct public funding, regardless of where the research is performed)

Research and Development, or **R&D** – Creative and systematic work undertaken in order to increase the stock of knowledge – including knowledge of humankind, culture and society – and to devise new applications of available knowledge

'Research publications', 'publications' and **'scholarly output'** refer to individual, published research documents, rather than to the journals in which they appear. Research publications are a subset of total scholarly output: Articles, Conference Papers and Reviews

'Scholarly output' refers to all the published research documents captured by the Scopus database

Small Advanced Economies (SAE) Initiative is a collaboration on science and innovation, and other areas, between Denmark, Finland, Ireland, Israel, New Zealand, Singapore and Switzerland. All of the countries are advanced economies of similar scale in terms of population with around 5 to 10m inhabitants

STEM – Science, Technology, Engineering and Mathematics. This usually refers to fields of study, fields of research or skills. The precise fields and disciplines included are not consistent in the different indicators in this report, due to variations in conventions used and availability of the source data

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Sources

FIGURE	TITLE	SOURCE
1	Publications per researcher	Scival.com, accessed 13 May 2018; OECD MSTI, accessed 9 Apr 2018
2	Publication per million dollars research expenditure	Scival.com, accessed 13 May 2018; OECD MSTI, accessed 15 Jan 2018; Statistics NZ R&D Survey 2016 (revised)
3	Proportion of publications in top ten per cent most-cited worldwide	Scopus custom data, extracted June 2017
4	Proportion of publications in top one per cent most-cited worldwide	Scopus custom data, extracted June 2017
5	New Zealand's total production share relative to the world in research volume and average citation impact	Scopus custom data, extracted June 2017
6	New Zealand's total production share relative to the world in research volume and publications in top percentile	Scopus custom data, extracted June 2017
7	New Zealand's total production share relative to the world in research volume and fraction which have of received at least one citation	Scopus custom data, extracted June 2017
8	Comparison of New Zealand's GDP per hour worked with Small Advanced Economies and Australia	OECD iLibrary, accessed 16 Apr 2018
9	Economic complexity ranking	https://atlas.media.mit.edu/en/profile/country/fin/, accessed January 2018
10	Proportion of firms that innovate	OECD Innovation Indicators 2017 http://www.oecd.org/sti/inno-stats.htm, accessed January 2018
11	Product innovations reported by firms	OECD Innovation Indicators 2017 http://www.oecd.org/sti/inno-stats.htm, accessed January 2018
12	Research cited by patents	Scival.com, accessed 30 May 2018
13	New Zealand publications cited in patents, by academic citation decile	MBIE analysis of data from Scival.com
14	Business expenditure on R&D	OECD MSTI, accessed January 2018
15	Business expenditure on R&D as a percentage of GDP	OECD MSTI, accessed January 2018; Statistics NZ infoshare Series GDP(E), Nominal, Actual, Total (Annual-Mar)
16	Share of R&D expenditure by Industry	Statistics NZ R&D Survey 2016
17	Total business expenditure on R&D by company size	Statistics NZ custom data based on R&D Survey 2016
18	Proportion of businesses doing R&D	Statistics NZ custom data based on R&D Survey 2016
19	Average expenditure by R&D performers	Statistics NZ custom data based on R&D Survey 2016
20	Business expenditure in R&D by top-spenders	Statistics NZ custom data based on R&D Survey 2016
21	How business R&D was funded	Statistics NZ R&D Survey 2016
22	Early stage capital investments and deals	Young Company Finance Index 2018; https://www.pwc.co.nz/pdfs/2018pdfs/startup-magazine-2018.pdf

FIGURE	TITLE	SOURCE
23	Angel investment across sectors 2006-2016	Young Company Finance Index 2017; http://www.nzvif.co.nz/assets/publications/START-UP-Issue-Apr17.pdf
24	Number of 'tech' starts-ups per hundred thousand people	Global Startup Genome Report 2017; Statistics New Zealand; Statistics Finland; Australian Bureau of Statistics; Israel Central Bureau of Statistics; Singstat. Department of Statistics Singapore
25	Venture Capital investments in US$ million and as a per cent of GDP	Entrepreneurship at a Glance 2017, OECD 2017
27	Total Expenditure on R&D as a proportion of GDP	OECD MSTI, accessed January 2018; Statistics NZ R&D Survey 2016 (revised); Statistics NZ infoshare Series GDP(E), Nominal, Actual, Total (Annual-Mar)
28	Total Expenditure on R&D	OECD MSTI, accessed January 2018; Statistics NZ R&D Survey 2016 (revised)
29	R&D by funder and performer	Statistics NZ R&D Survey 2016 (revised)
30	Business, Government and Higher Education expenditure on R&D	Statistics NZ R&D Survey 2016 (revised)
31	Government expenditure on R&D as a proportion of GDP	OECD MSTI, accessed January 2018
32	R&D performed by Government	OECD MSTI, accessed January 2018
33	Higher education expenditure on R&D & No. of Publications	OECD MSTI, accessed January 2018; Statistics NZ R&D Survey 2016 (revised); Scopus custom data, extracted June 2017
34	R&D growth by sector of performance	OECD MSTI, accessed January 2018; Statistics NZ R&D Survey 2016 (revised)
35	Public Funding of R&D as a proportion of GDP	Government Estimates of Appropriations 2018/19, supplemented by departmental forecasts; Statistics NZ infoshare Series GDP(E), Nominal, Actual, Total (Qrtly), for June YE GDP; Budget Economic Forecast 2018
36	Total public support for research, science and innovation	Government Estimates of Appropriations 2018/19, supplemented by departmental forecasts
37	Public funding by mechanism, actual and forecast	Government Estimates of Appropriations 2018/19, supplemented by departmental forecasts
38	Expenditure on R&D by purpose of research and sector of expenditure	Statistics NZ R&D Survey 2016 (revised)
39	Proportion of research expenditure by type	OECD MSTI, accessed January 2018
40	Proportion of capital and current expenditure on R&D	OECD MSTI, accessed January 2018
41	Number of Researchers (Headcount)	OECD MSTI, accessed January 2018
42	Researchers per 1000 employment	OECD MSTI, accessed January 2018
43	Researchers by sector	Statistics NZ R&D Survey 2016 (revised)
44	Proportion of male and female researchers by field in the tertiary sector	Women in Science: A 2011 Snapshot, Association for Women in the Sciences (2011) http://www.awis.org.nz/wis-in-nz/statistics/; PBRF Quality evaluation custom data

FIGURE	TITLE	SOURCE
45	Domestic students completing doctoral degrees by gender, 2016	www.educationcounts.govt.nz
46	Domestic students completing doctoral degrees by gender, 2008-2016	www.educationcounts.govt.nz
47	Doctoral degree completions by ethnic background	www.educationcounts.govt.nz; Statistics NZ population projections [for additional data in text]
48, 49	Scores on Trends in International Mathematics and Science Study	timss2015.org
50, 50a	Proportion of School Leavers achieving at least 14 credits in specified subjects	Ministry of Education Custom Data
51	Proportion of graduates who are in STEM subjects	World Development Index; Ministry of Education Custom Data
52	People completing qualifications in STEM fields	Ministry of Education Custom Data
53	Inward migration of STEM professionals	Statistics NZ Infoshare Series: Permanent & long-term migration by ctry of residence, occupation
54	Inward migration of Science professionals	Statistics NZ Infoshare Series: Permanent & long-term migration by ctry of residence, occupation
55	Proportion of publications with more than one author	SciVal.com, Date exported-17/01/18
56	Collaborations between different types of New Zealand research organisation	Scopus custom data, accessed June 2017
57	Number and citation performance of institutional collaborations	Scopus custom data, accessed June 2017
58	Proportion of scholarly output with international co-authorship	Scival.com, accessed January 2018
59	Number and proportion of New Zealand publications with international co-authorship by field	Scopus custom data, accessed June 2017
60	World average of international collaboration rates in certain fields	Scopus custom data, accessed June 2017
61	Proportion of publications with academic-business collaboration	Scival.com, accessed January 2018
62	Proportion of research in higher education funded by business	OECD MSTI, accessed January 2018
63	Businesses that cooperate on innovation	Statistics NZ Business Operations Survey 2017