Science & Innovation System Performance Report

2016

MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
HĪKINA WHAKATUTUKI

New Zealand Government

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Minister's foreword

I am pleased to release this first Science and Innovation System Performance Report. New Zealand invests a considerable amount in science and innovation because it has huge potential returns for our economic, environmental, health and social wellbeing. This report is the first in a series of annual updates on the impact this investment is having.

We need to fully understand the science and innovation system to ensure it is high performing. The National Statement of Science Investment, released last year, committed to a transparent and high performing science system, including annual system performance reports. Robust data on performance will increase confidence that government investment is delivering good value-for-money and that policy settings are optimal for the system as a whole. This is especially important given the Government's investment of $411 million additional science and innovation funding through the Innovative New Zealand package in Budget 2016.

This first report is a step towards a comprehensive evaluation, monitoring and reporting system. The Ministry of Business, Innovation and Employment recently published the Research, Science and Innovation Domain Plan: a roadmap to creating a rich, cross-government database on research. This will allow continuous improvement of the data and analysis of performance presented in future system performance reports.

This report highlights some of the New Zealand science and innovation system's impacts, strengths and weaknesses and how the system is changing over time. The government is one of many actors in science and innovation. I would like this report to stimulate conversations across the sector about how to make the system better.

Hon Steven Joyce
Minister of Science and Innovation

November 2016

Introduction

ABOUT THIS REPORT

This document is the first in what will be an annual report series. The reports will show how the New Zealand science and innovation system is performing in key areas. They will cover the relevant people, skills, knowledge, infrastructure and funding across government, education and business. This includes the outputs of research activity, such as scientific publications, and the impacts of science and innovation on outcomes which New Zealanders value.

This report responds to the National Statement of Science Investment's (NSSI) vision of: "*. . .comprehensive evaluation and monitoring of performance, underpinned by easily available, reliable data on the science system. . .*".

We are particularly interested in the impacts the science and innovation system creates for the economy, health, society and the environment. Impact is the eventual effect of science and innovation. It is difficult to measure because of the many pathways by which it can occur, the many drivers of socio-economic outcomes and the time lags in the system. The reports will tackle this by presenting deeper analysis in different focus areas as well as case studies on particular scientific breakthroughs. Over time, this will allow us to build up a picture of the links between system activities and outcomes for New Zealand.

The report series is intended to be a resource for the many people and institutions who contribute to the performance of the science and innovation system. It will:

- increase transparency by publishing regular data on expenditure, outputs, impacts and performance of the science and innovation system
- provide a single evidence base to inform government policy decisions and longer-term strategy
- report on progress against goals in the National Statement of Science Investment
- highlight strengths, weaknesses, and opportunities in the system and stimulate discussion among policymakers, funders, researcher institutes, businesses and 'end-users' to improve system performance.

We are working to improve the coverage and reliability of data available on the science and innovation system. Over time, this will allow us to expand the set of indicators and provide analysis in areas where there are currently data gaps.

SCIENCE AND INNOVATION IN NEW ZEALAND

New Zealand invests in science and innovation because it is fundamental to improving our economic, environmental, social and cultural outcomes. 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. Research and development increase the stock of useful knowledge, build a more skilled population, create new products and services, and stimulate new networks for sharing knowledge[1].

New Zealand has a number of specialisms in specific fields of health research and medical technologies. We also face a number of challenges including our poor child health outcomes and ageing population. Health research in New Zealand can result in better treatments and health interventions, and new drugs of benefit here and globally, as well as economic benefits through growth in health-technology industries.

New Zealand's unique geography, biological heritage and natural resources have made it a fertile setting for science relating to the environment, natural hazards, and agricultural production. Our identity, wellbeing, safety and economy depend on the environment and our interactions with it. Science can help us manage natural resources sustainably and mitigate natural hazard risks. Such science tends to have broad long-term public benefits, rather than short-term focused private benefits.

Successive waves of human arrivals in New Zealand have created a unique cultural heritage including mātauranga māori and western scientific knowledge. The Vision Mātauranga policy framework aims to unlock the innovation potential of Māori knowledge, resources and people by providing strategic direction for government-funded research of relevance to Māori[2].

The broader economic and regulatory environment sets the context for science and innovation. New Zealand is considered an easy place to do business and innovate by international standards. On the other hand our small size, distance from international markets and particular industry structure pose some challenges for our rates of R&D investment and innovation, and our ability to tap into global markets and knowledge.

STRATEGY DOCUMENTS

The National Statement of Science Investment

The National Statement of Science Investment (NSSI), published in October 2015, sets out the Government's vision for 2025:

> *"A highly dynamic science system that enriches New Zealand, making a more visible, measurable contribution to our productivity and wellbeing through excellent science."*

This includes:

- a better-performing science system that is larger, more agile and more responsive, investing effectively for long-term impact on our health, economy, environment and society
- growth in BERD to well above 1 per cent of GDP, driving a thriving independent research sector that is a major pillar of the New Zealand science system
- reduced complexity and increased transparency in the public science system
- continuous improvement in New Zealand's international standing as a high-quality R&D destination, resulting in the attraction, development and retention of talented scientists, and direct investment by multinational organisations
- comprehensive evaluation and monitoring of performance, underpinned by easily available, reliable data on the science system, to measure New Zealand's progress towards these goals.

The Business Growth Agenda

The Business Growth Agenda (BGA) Innovation Chapter, 2015, sets a vision of developing New Zealand as a hub for high-value, knowledge-intensive businesses which create value through innovation (including R&D). Key priorities in addition to those in the NSSI include:

- attracting multi-national R&D investment
- strengthening New Zealand's innovation infrastructure
- making the most of the digital economy
- ensuring regulations support innovation
- growing innovation skills.

The Tertiary Education Strategy

The Tertiary Education Strategy covers a wide range of issues. Key priorities relating to science and innovation are:

- **Delivering skills for industry** – ensuring that the skills people develop in tertiary education are well matched to labour market needs, including addressing emerging shortages in skills important for innovation and economic growth, such as information and communications technology (ICT) and the science, technology, engineering and mathematics (STEM) subjects.
- **Strengthening research based institutions** – including closer collaboration between universities, other research organisations and industry.

These science and innovation system performance reports will track how New Zealand is doing in terms of building on our existing scientific strengths, overcoming our particular challenges, and ensuring the work of scientists and innovative firms leads to positive impacts in areas which are relevant and important for New Zealanders.

MEASURING PERFORMANCE

Understanding how well the science and innovation system is working – its 'performance' – is only possible if we understand how the system *should* work. There are many competing theories on this. The science and innovation system is complex, with a number of connected components. For the purposes of this report, we have developed a framework that builds on the conceptual framework that was first presented in the draft NSSI.

Figure 1 is a stylised illustration of how we think about the science and innovation system. Each component in the diagram is covered in this report.

Section 1 covers the results and impacts we are seeing from the New Zealand science and innovation system in terms of **new knowledge** and **innovation activity**. It compares New Zealand's **science quality** to international benchmarks, identifies some **areas of expertise**, examines **private sector R&D** and describes **impacts** for economic, environmental, health and social, outcomes.

Section 2 measures the **funding, people** and **infrastructure** that support science and innovation. Dollar values are given in nominal terms (i.e. not adjusted for inflation) unless otherwise stated.

Section 3 covers some of the supporting factors for R&D: the **skills pipeline, connections** between researchers, organisations and end-users, and the **economic and regulatory environment**.

Section 4 assesses overall performance against specific NSSI goals and more broadly.

The report presents indicators of the volume and quality of science and innovation activity across these system components. Further breakdown (e.g. by research field or institution type) is given to understand drivers of trends and patterns in some areas.

The Small Advanced Economies, Australia and the OECD are used as benchmarks for performance on many indicators. The Small Advanced Economies Initiative is a collaboration, including on science and innovation, 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 10 million inhabitants.

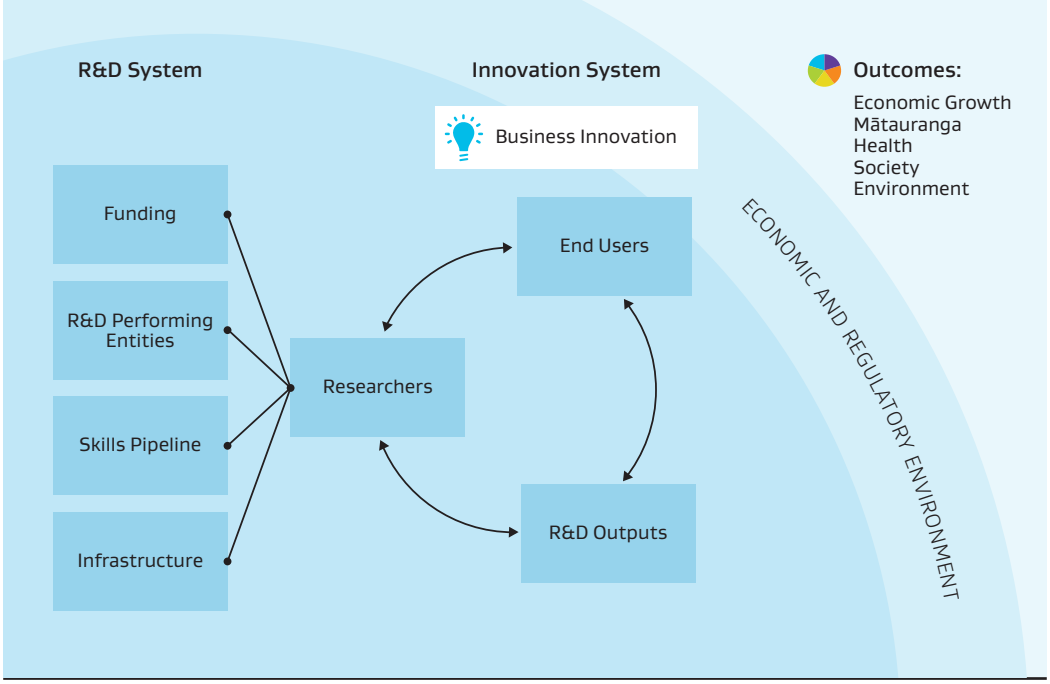
HOW WE THINK THE SYSTEM WORKS

Understanding how well the science and innovation system is working – its 'performance' – is only possible if we understand how we think the system *should* work. There are many competing theories on this. The science and innovation system is complex, with a number of connected components. For the purposes of this report, we have developed a framework that builds on the conceptual framework that was first presented in the draft NSSI.

Figure 1, is a stylised illustration of how we think about the science and innovation system. Appendix 1 shows a more detailed version. This framework has been used to structure and guide the analysis in this report.

The data and analysis presented in this report series will gradually improve our understanding of the system over time. We expect future iterations of this report to contain a more detailed and nuanced view of the interaction between the science and innovation areas.

Figure 1: The New Zealand Science and Innovation System



Section 1:

Results and impacts

Research outputs

Outputs, such as scientific journal publications, are the immediate deliverable from research. They embody and communicate the new knowledge generated by research work. 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.

Journal publications are a key output and one for which we have good data. Other important outputs exist, including reports by CRIs to their clients (around 1500 to 2000 of these are delivered each year).

TOTAL SCHOLARLY OUTPUT

What it measures

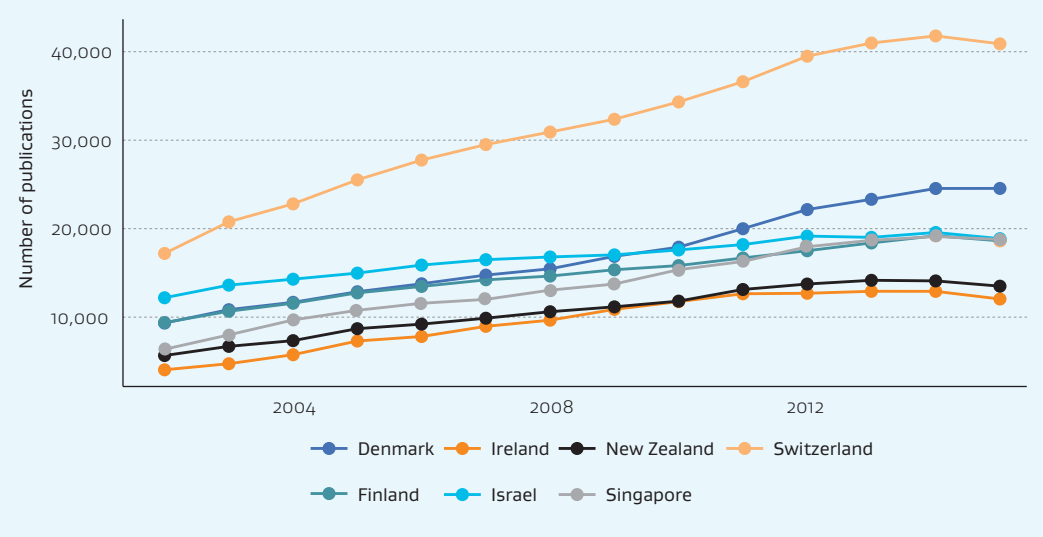
This shows the volume of scholarly output across all research fields. This includes articles, reviews, editorials, short surveys and conference papers.

Why it matters

Publications are the main, immediate output of most research. Outputs per $ research funding is an indicator of the efficiency of the science system.

What the data show

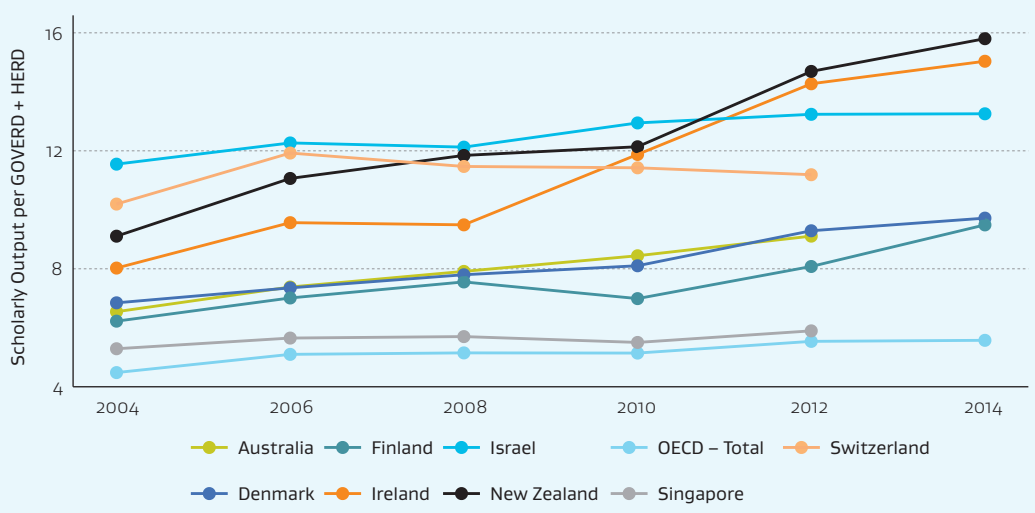
Figure 2 Scholarly output



New Zealand's scholarly output is low among the Small Advanced Economies. This is in part a reflection of New Zealand's lower investment in research funding. Output has steadily grown across all these countries over the last 13 years.

New Zealand does well on outputs per $ of research funding* – around three times the OECD average and top among the Small Advanced Economies.

Figure 3 Scholarly output per $m research expenditure (excluding business expenditure; 2010 PPP USD)

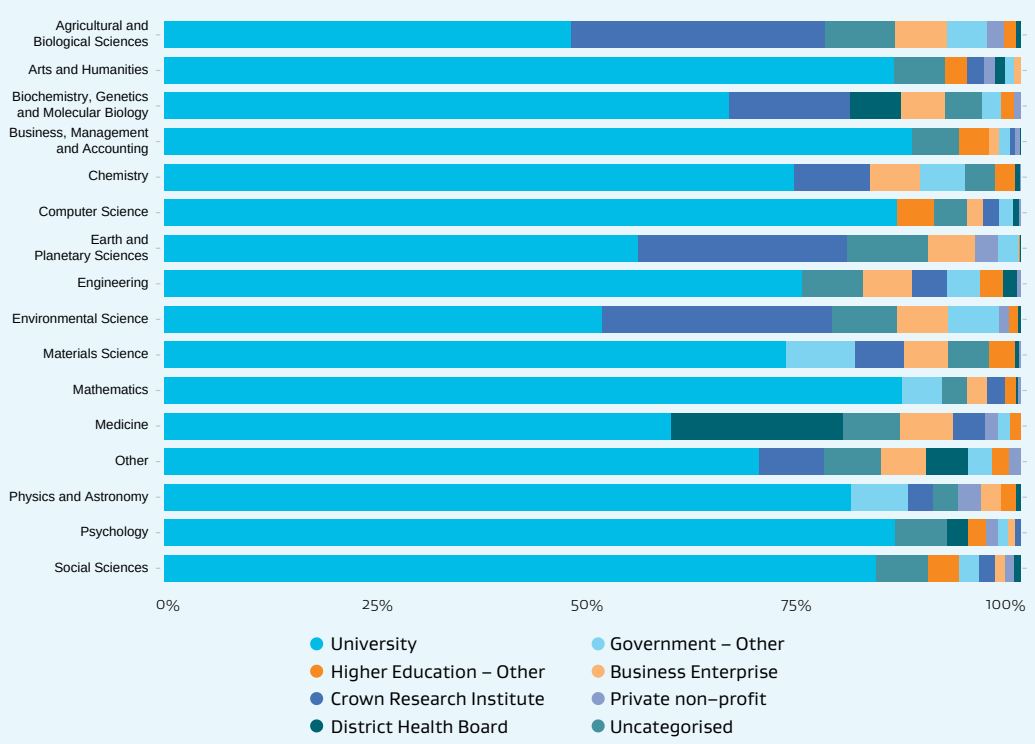


* Note this indicator is based on total research outputs divided by GOVERD and HERD funding only. These are the funding types most likely to result in a publication. Including BERD would increase New Zealand's apparent relative research productivity even further, but this is mainly a result of New Zealand's relatively lower BERD spend.

BREAKDOWN: PUBLICATIONS BY INSTITUTION TYPE BY SUBJECT AREA

Figure 4 is a breakdown of New Zealand publications from 2010-2014 by institution type and ASJC research field (All Science Journal Classification). These data show the dominance of universities in academic publishing across all fields. CRIs contribute in specific areas, reflecting their areas of expertise. Business contributes across all fields.

Figure 4 Contribution to research fields by different sectors



SHARE OF TOP PERCENTILE RESEARCH

What it measures

This indicator shows the proportion of New Zealand's publications (primarily journal articles, reviews and conference papers) that appear in the top 10 or 1 per cent most-cited academic outputs (in the same field) worldwide.

Why it matters

This is an indication of how influential New Zealand research is on the world stage.

Citations are widely recognized as a useful, if imperfect, proxy for quality. Some limitations are:

- 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.
- Citations have a highly-skewed distribution (i.e. a few papers receive hundreds or thousands of times more citations than the majority of papers). This makes average citations received an incomplete summary of overall performance and they should be considered with other measures of the distribution of citation (e.g. papers in top 10 per cent most-cited).

What the data show

Of the articles with New Zealand authors in 2014, 14.1 per cent were in the top 10 per cent by citations worldwide. If citations were equally distributed across publications, New Zealand would expect to receive 10 per cent on this measure. This score shows New Zealand has about 40 per cent more highly-significant publications than would be expected if all countries' publications were equally influential.

New Zealand remains consistently ahead of the OECD average on this measure (outputs in top 10 per cent), fairly close to Israel, Ireland , Finland and Australia, but behind Denmark, Singapore and Switzerland. These results suggest that New Zealand's high research output per dollar is not obtained at the expense of research quality.

Similar results are seen for New Zealand's production of extremely influential publications (top 1 per cent). 1.4 per cent of New Zealand 2014 publications currently appear in the top 1 per cent of cited publications worldwide (field-weighted). Similarly to top-decile research, we are slightly above the OECD average, but trail other Small Advanced Economies on this measure.

Figure 5 Proportion of country publications in top 10 per cent most-cited in their field worldwide

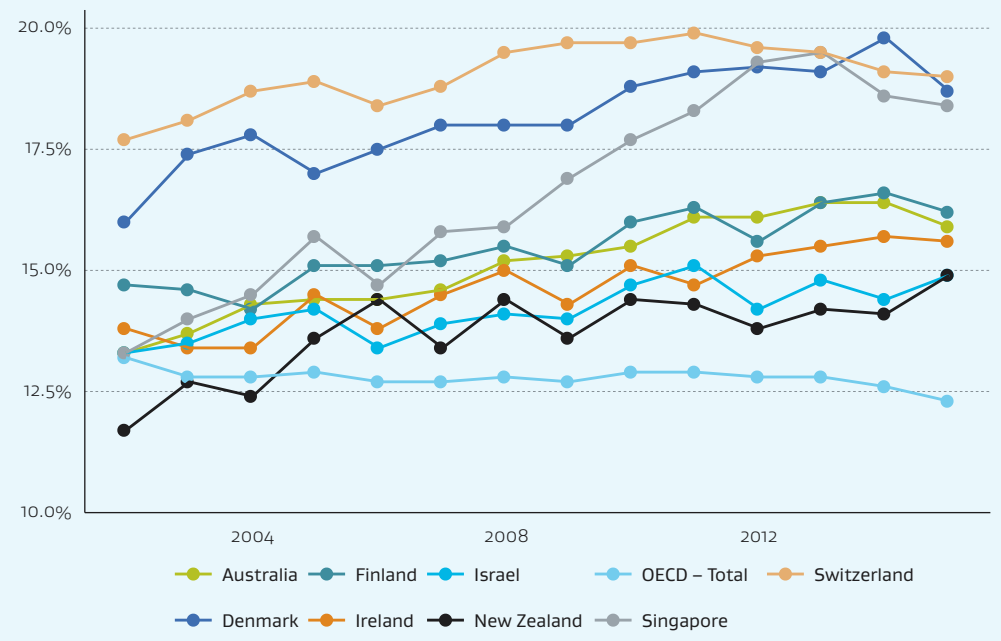
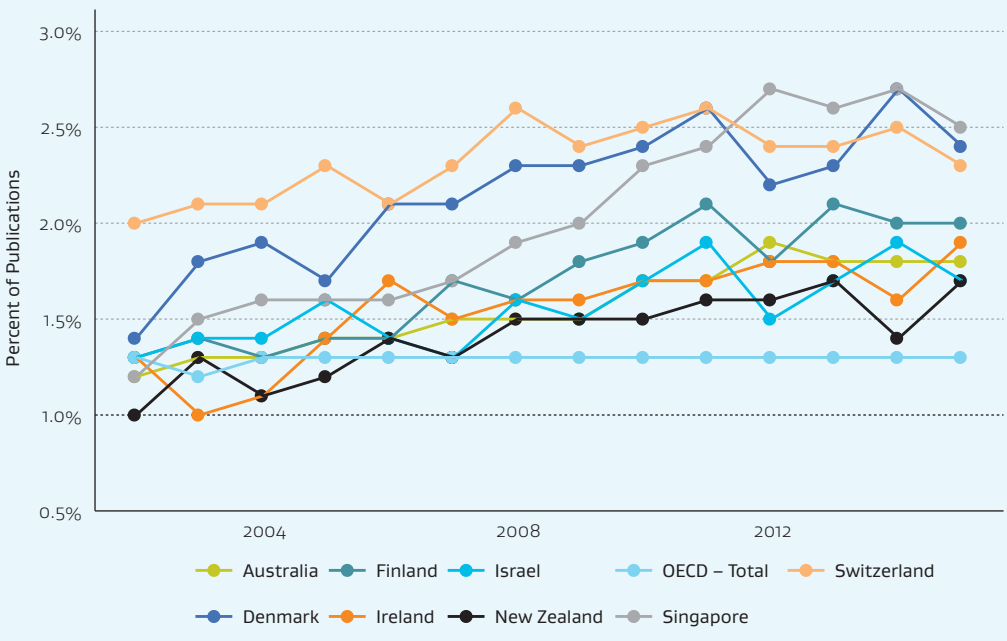


Figure 6 Proportion of country publications in top 1 per cent most-cited in their field worldwide



FIELD-WEIGHTED CITATION IMPACT FOR NEW ZEALAND PUBLICATIONS (BY FIELD)

What it measures

Field-weighted citation impact (FWCI) is the citations received per publication, in the three years following publication, compared with the average citations per publication for that field worldwide. The worldwide value in each field is equal to 1 (by definition). Values above 1 indicate above-average citation impact.

Why it matters

This is a measure of average influence of research outputs on the world stage. FWCI can be boosted by a large number of moderately-cited outputs or a few very highly-cited outputs. It is important to consider it alongside other measures (such as proportion of outputs in top 10 per cent and 1 per cent most-cited) to get a more complete picture.

When calculating citation statistics, a publication's research field is taken to be that of the journal in which it is published. This creates strange results for multidisciplinary research, whose citation statistics are strongly affected by publications in the top-cited (multidisciplinary) journals Nature and Science. For this reason the multidisciplinary category is excluded from Figure 7.

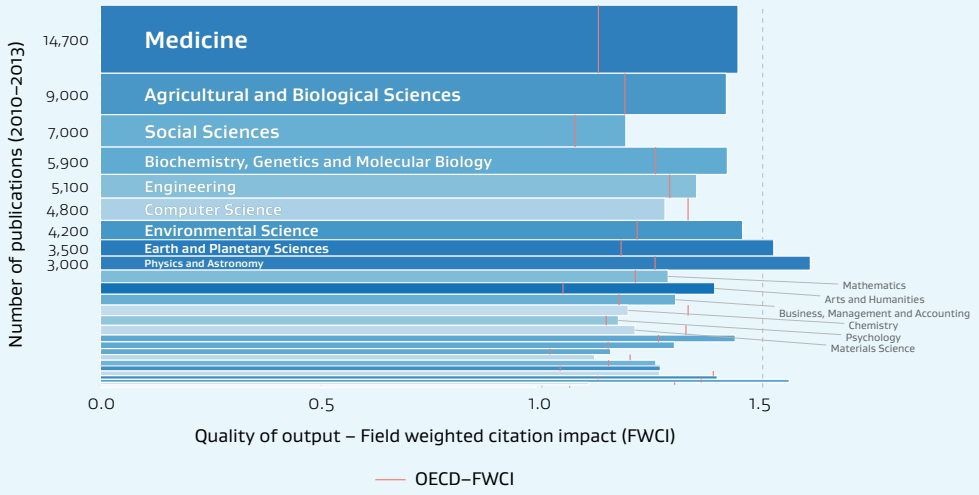
New Zealand achieves more than its fair share of publications in Nature and Science: 0.17 per cent of our publications appear in Science or Nature, compared with only 0.11 per cent of global publications. Future reports may include indicators on publications in top journals to complement other bibliometric measures.

What the data show

New Zealand produces high volumes of research in Medicine, Agricultural and Biological Sciences, and Social Sciences. In most research areas our publications are relatively well-cited: in all cases we score higher than the world average for each field (1.0).

When compared to the overall OECD field weighted citation impact (the red line in each field) we mostly fare well, but lag the OECD in Computer Science, Chemistry and Materials Science.

Figure 7 Field weighted citation impact (FWCI) and volume of publications for New Zealand. Orange line indicates OECD FWCI.



New Zealand's scientific specialisation

New Zealand has certain areas of scientific specialisation, as do other countries.

New Zealand publishes over half its output in just five fields (Medicine; Agricultural and Biological Sciences; Social Sciences; Biochemistry, Genetics and Molecular Biology; and Engineering). However, this does not show the whole picture. Some fields (such as Medicine) publish far more papers globally than others. A large output by New Zealand in Medicine does not necessarily indicate a specialism. In Figure 8 the area of each box shows the volume of output for that field in each of the Small Advanced Economies – revealing that all but one have Medicine as their most prolific field.

We can correct for this effect by calculating New Zealand's fraction of papers in a particular field relative to the global fraction in that field, to show the 'revealed advantage'*. Figure 9 shows the result for New Zealand. The colouring of this diagram indicates the relative quality of our outputs – the average citations received per publication relative to the world average#.

These field-weighted output data reveal that New Zealand's relative specialisms are in a broader range of fields than the simple output data would suggest. The top nine (rather than five) fields consitute just over half of the total 'weighted output'. Agriculture remains but Medicine no longer figures as a relatively large share of New Zealand's output. Other specialisms are revealed including in Business, Management and Accounting; Veterinary; Health Professions; Psychology; and Economics. These are fields in which New Zealand does relatively more research than the OECD average.

In Figure 10 the colouring shows the fields where New Zealand has some really excellent research – publications which appear in the top 1 per cent of cited work for that field worldwide. Now, another set of very niche specialisms is revealed – in Engineering; Physics and Astronomy; Computer Science; and Energy research.

New Zealand's research effort does not appear to be optimally matched with the areas in which we produce the highest-quality research. On the other hand, impact is important as well as excellence. New Zealand's current focus of research effort on Agriculture, Veterinary, Health Professions, Environmental Science, and Earth and Planetary Sciences probably reflects New Zealand's economy, society and environmental (including geological) challenges.

The niche expertise in areas relating to technology and IT suggest opportunity for these to contribute to economic diversification in these high productivity sectors. Basic ICT research is an area where the NSSI committed to increasing investment over time.

* This is analogous to the 'field-weighting' approach used to calculate the field weighted citation index and also to the approach used in economics to calculate a countries 'revealed comparative advantage' in a particular product from international trade data.

\# Note that these data are from the Scopus publications database. Coverage of Social Sciences, Arts and Humanities is limited in this database, particularly for journals in non English-speaking countries. Therefore results in these areas may not be fully representative of New Zealand's global performance.

Figure 8: Volume of publications (size of boxes) and number of citations received (shading) in Small Advanced Economies, 2010–13

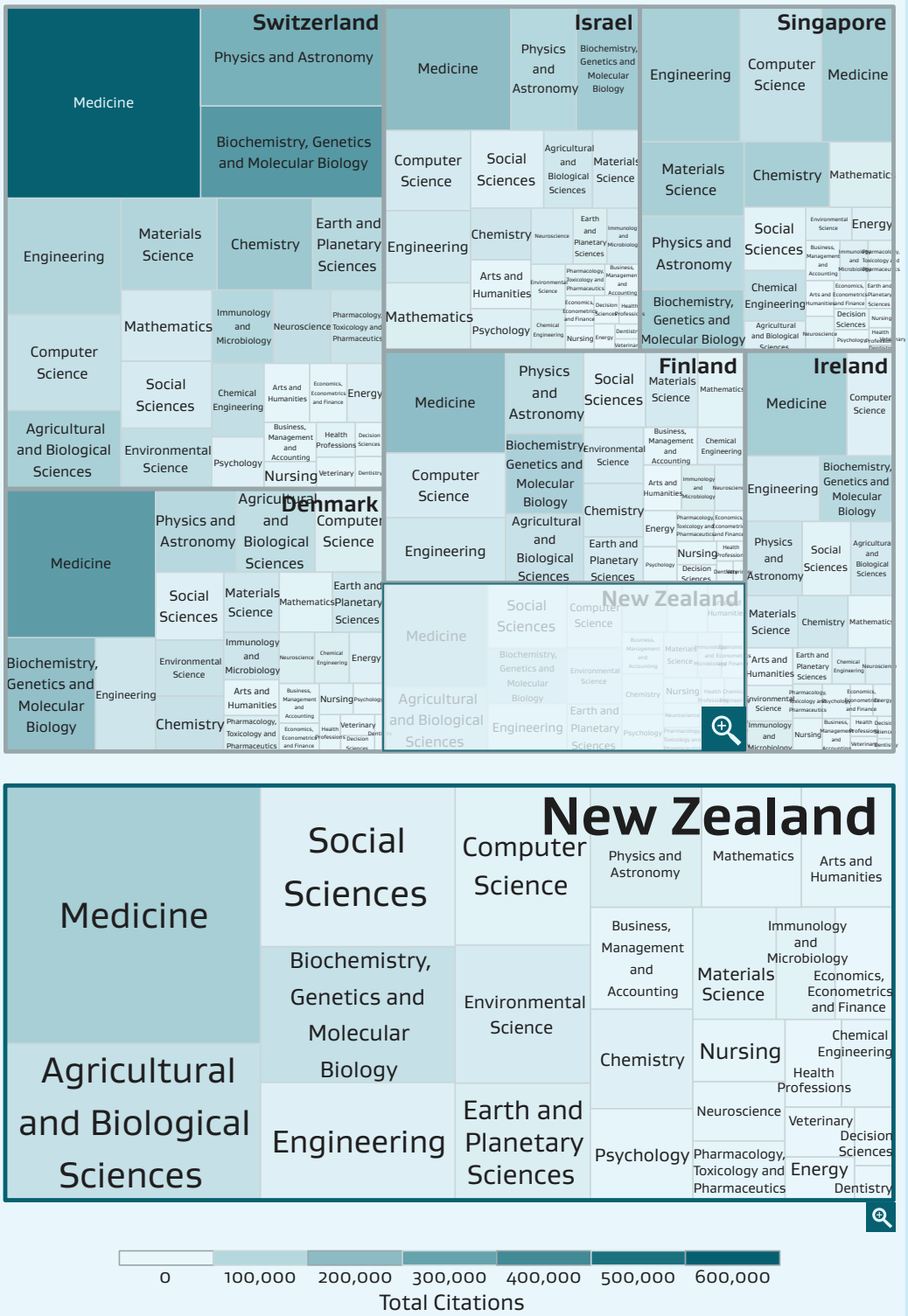


Figure 9: New Zealand's revealed comparative advantage in research volume (size of box) and average citation impact (shading), 2010–13
New Zealand publishes a higher share of its research outputs than the world average in fields above and to the left of the thick line.

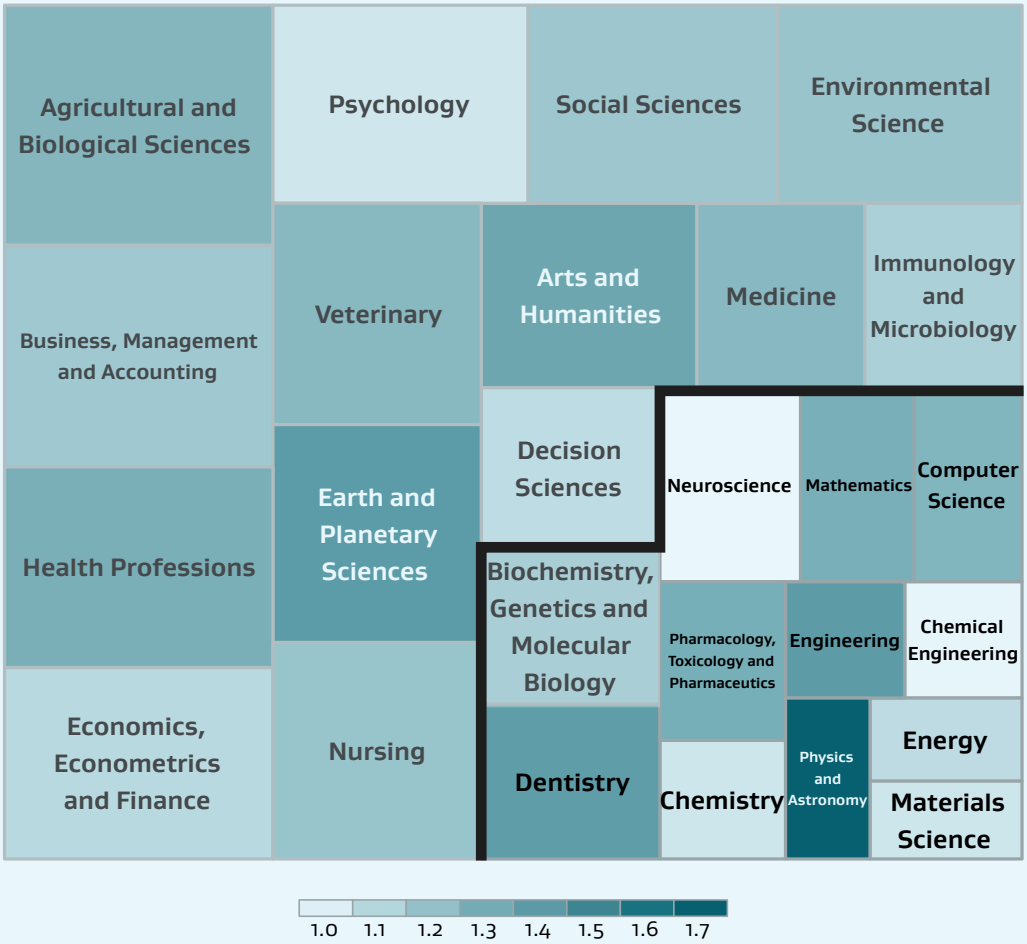
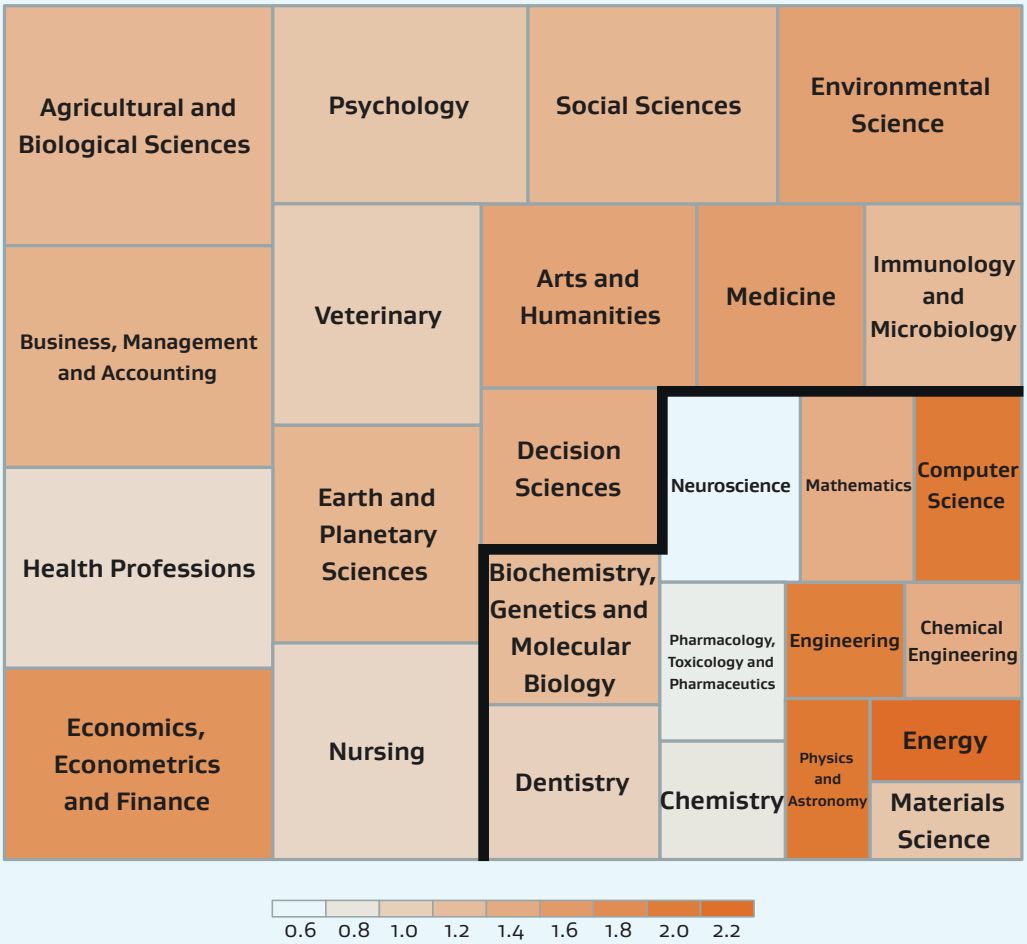


Figure 10 New Zealand's revealed comparative advantage in research volume (size of box) and publications in top 1% most-cited for the field (shading), 2010-13
New Zealand publishes a higher share of its research outputs than the world average in fields above and to the left of the thick line



Semantic analysis of research descriptions

COMBINED ANALYSIS OF ENDEAVOUR, MARSDEN AND HRC RESEARCH: 2008-15

The Endeavour Fund (and its predecessors), the Marsden Fund and the Health Research Council (HRC) have invested in a large number of research projects through (mainly) contestable funding mechanisms over the years. Because of changes to funding mechanisms and data gathering and coding processes over time, it is challenging to produce a systematic view of what sorts of science have been funded.

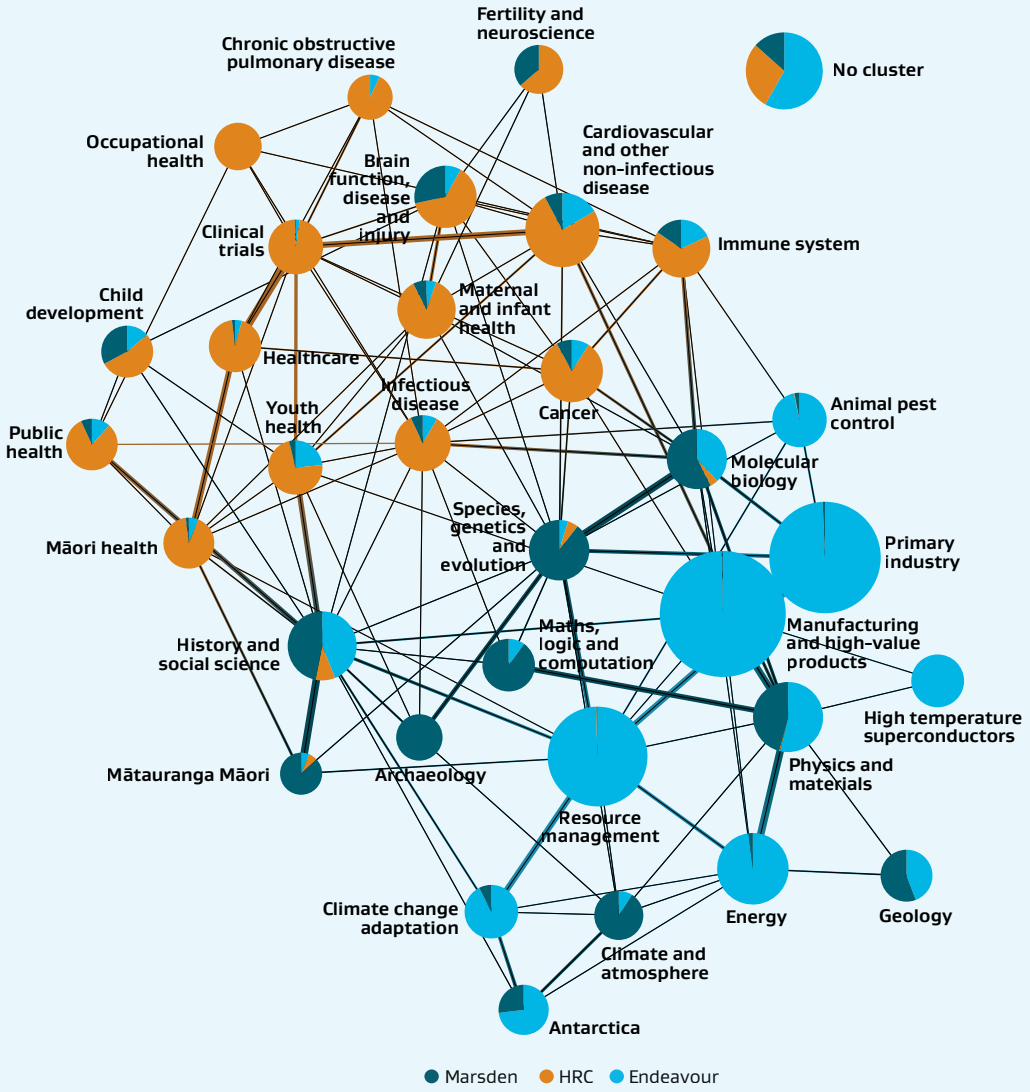
New algorithms for semantic analysis offer a powerful way of analysing historical science contract data. Figure 11 shows a semantic analysis of research funded between 2008 and 2015 by Endeavour (and predecessors), Marsden and the HRC (Health Research Council).

The semantic analysis software is applied to project research descriptions. Projects which share key words and phrases are then grouped and appear in the same node in the network. The size of each node is roughly proportional to the total dollar value invested and the pie charts indicate how this is split between funds in each research area. Links between nodes indicate that the nodes share some key words, suggesting related research areas. Nodes in the centre of the diagram are more highly connected, while those on the periphery are less so.

The analysis emphasises the dominance of Endeavour in Primary industry, Manufacturing and Resource Management and of Marsden in more basic research in related areas.

Note that this analysis does not reflect the total allocation of funding across research areas, as it excludes other significant public research funding mechanisms, i.e. CRI Core Funding (within the Strategic Science Investment Fund) and Primary Growth Partnerships. Including these would increase the relative investment shown in Primary industry and Resource management areas.

Figure 11 Research areas and relationships between Endeavour, Marsden and HRC research, 2008–15



The objectives of the different funding mechanisms mean that Marsden tends to fund more basic research, while Endeavour research tends to be closer to application, and HRC research spans a range of research horizons. The data show several nodes where all three funds are contributing across their respective research horizons, especially in the health space (e.g. Child development and Brain function, disease and injury).

The links only indicate similarity in research descriptions, not necessarily links between the research performed. A key question these findings raise is whether New Zealand researchers under different funds in the same or related research areas are collaborating or building off each other's findings. New Zealand research institutions and funders are in the process of adopting the ORCID system of unique researcher identifiers. This will enable this sort of question to be answered in future reports.

Figure 12a shows semantic analysis applied to Endeavour research, with the pie charts on each node showing the split of funding received by type of research intuition.

This analysis reveals a strong emphasis on research over the last eight years relating to primary industry and the environment. A smaller portion of research has been directed towards high-tech areas and manufacturing. High value-natural resource products form a link between these areas.

CRIs have focused on the primary industry and environment side, while universities and Callaghan Innovation have focused on high-tech areas. Primary industry research associations and consortia (included in the 'Other' category) are common research funding recipients in Livestock and forage, High value natural resource products and Foodcrops development areas.

Figure 12a Research areas and relationships between Endeavour research areas, 2008-15

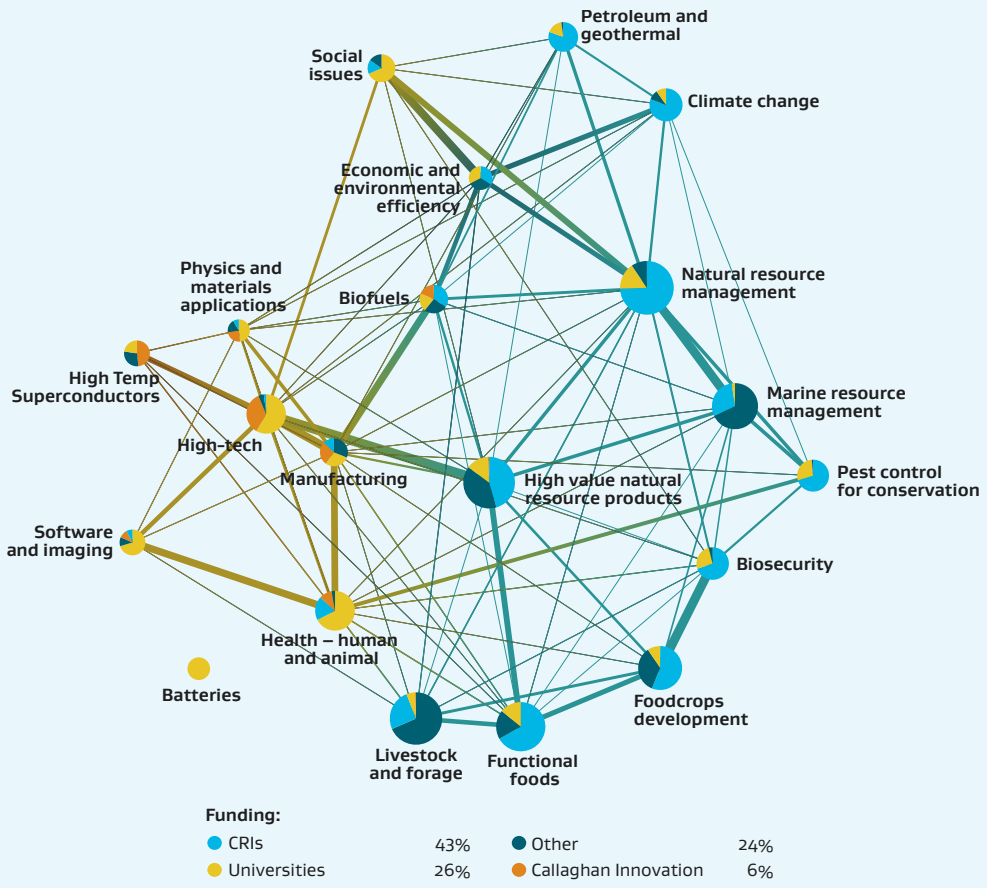


Figure 12b shows semantic analysis of Marsden-funded research. The results indicate the dominance of universities in the more fundamental, investigator-led type of research, which is funded by Marsden. Unlike Endeavour, research is broadly spread across different areas, rather than being focussed on primary industry and resource management.

Figure 12b Research areas and relationships between Marsden research areas, 2008–15

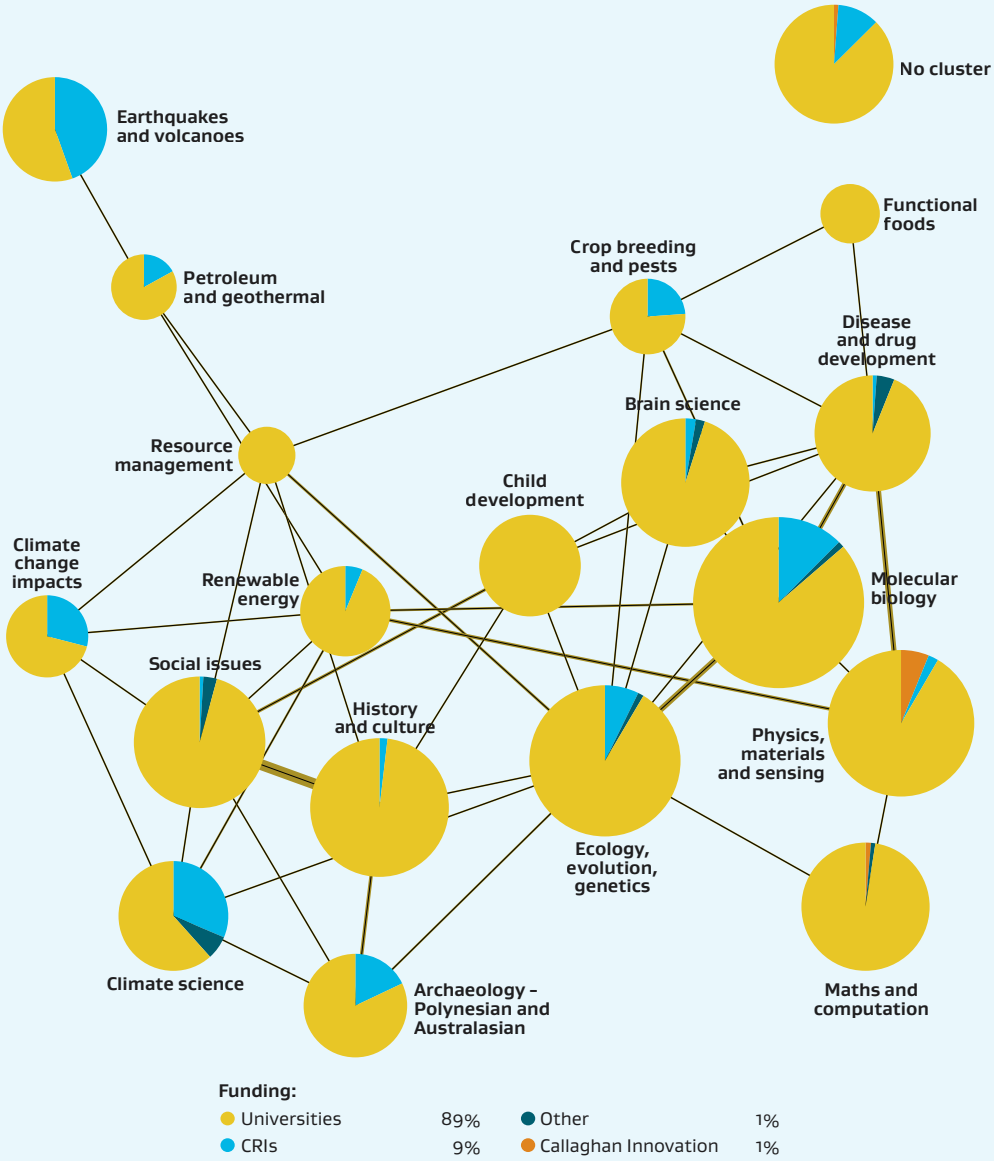
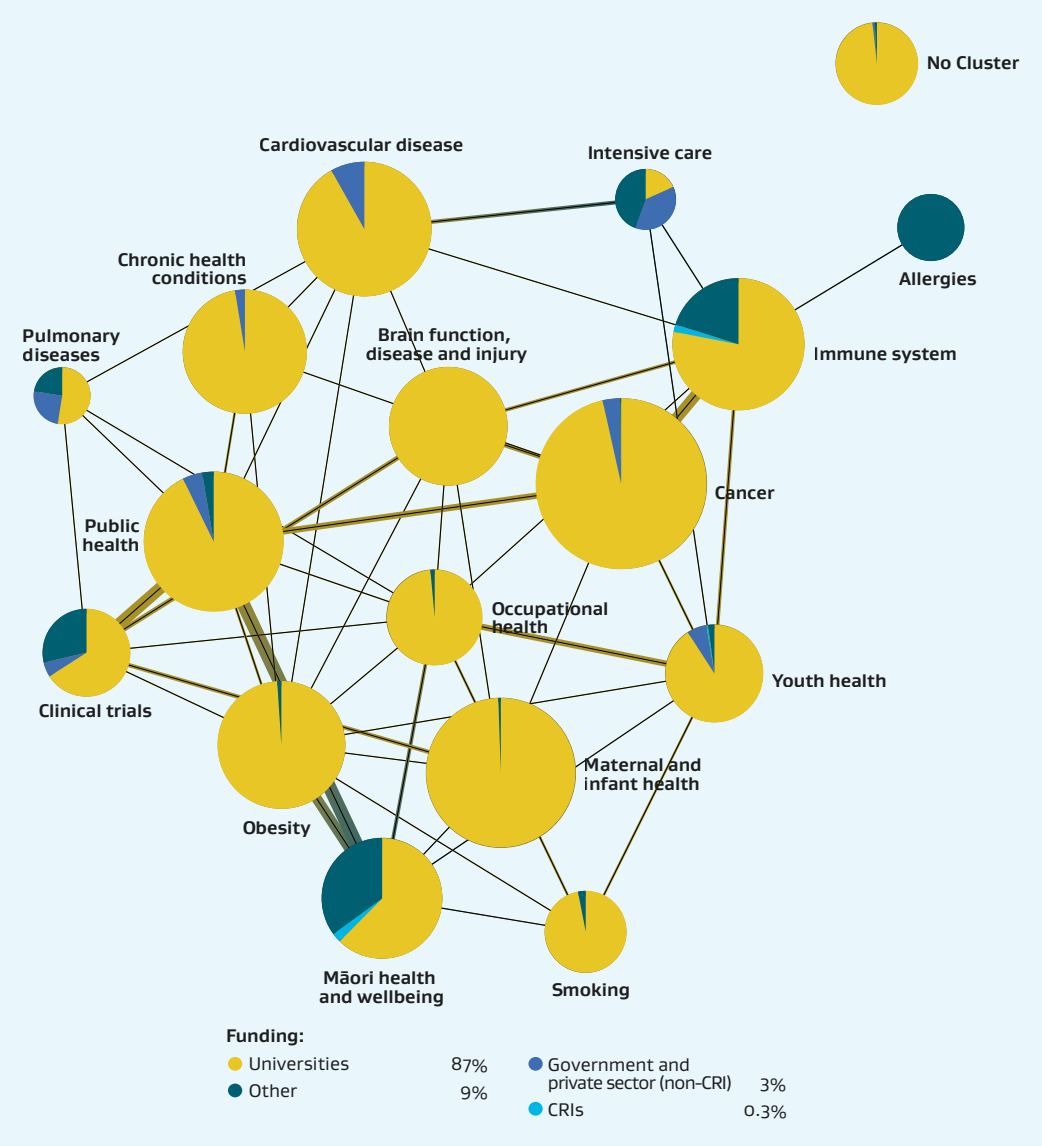


Figure 12c shows semantic analysis of HRC funded research. These semantically derived categories differ from standard classifications of health research. Although this allows the data to be analysed together with Endeavour and Marsden data to reveal the crossovers between the funds, the descriptions and funding allocation to the health research areas shown should be taken as illustrative only.

The analysis shows the dominance of universities in most health research areas – primarily Auckland and Otago medical schools. Within the 'Other' research institute category, Independent Research Organisations are important in the allergy and intensive care areas, while iwi based organisations are researching in the Māori health space.

Figure 12c Research areas and relationships between HRC research areas, 2008–15



Innovation

Innovation is the introduction of new or significantly improved goods, services, processes, or marketing methods. This is an OECD definition which relates to measuring private sector innovation.

The private sector is a key channel by which science and innovation yield economic benefits and is an area where we have good indicators and data. Business innovation can lead to improved profits and productivity and benefits to consumers from new products. In the longer-term, more innovative firms may gain an extra share of export markets and raise overall economic productivity.

Innovation in other sectors, such as health, education or public service provision, is likely to lead to impacts for health, environmental and social outcomes. International frameworks for measuring public-sector innovation are not well developed and New Zealand data are not available. Developing indicators in this area will be a key challenge for future system performance reports.

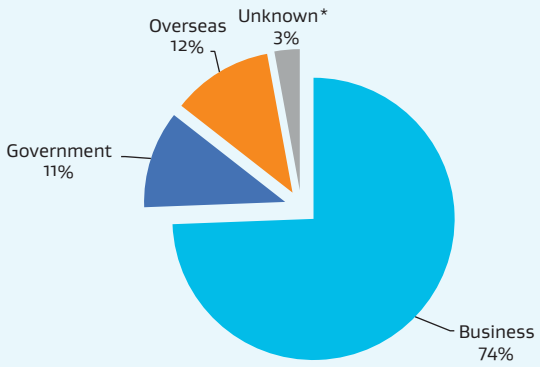
BUSINESS EXPENDITURE ON R&D (BERD)

What it measures

BERD measures business expenditure on R&D, regardless of the source of those funds. In many countries this includes significant government support for business R&D through co-funding schemes and tax-credits.

In New Zealand, around three-quarters of BERD is funded by business itself, with the remainder split between government and overseas funding.

Figure 13 How business expenditure on R&D is funded (2014)



Why it matters

BERD is often used as an indicator of the amount of innovative activity within businesses. R&D within businesses is understood to generate the knowledge base needed to develop new processes and products which can raise industry productivity.

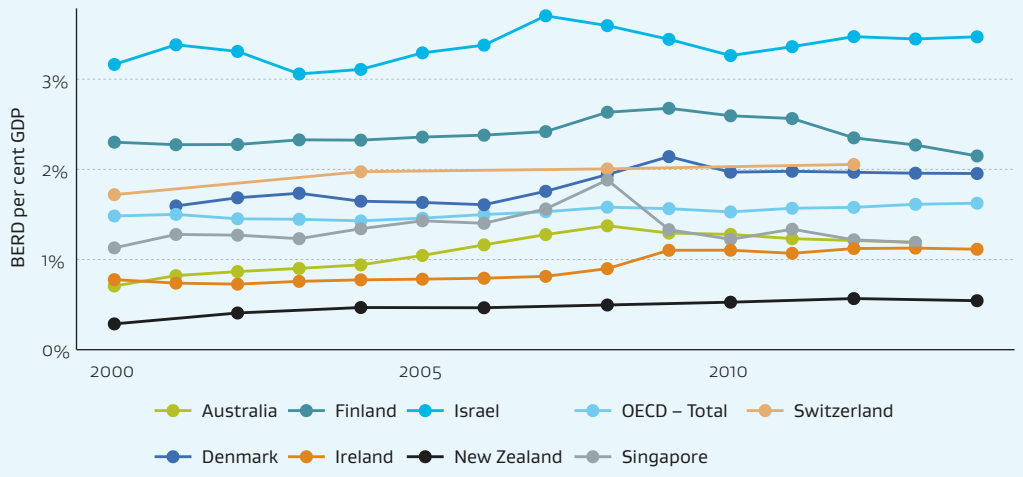
What the data show

New Zealand has low expenditure by business on R&D as a proportion of GDP by OECD standards and compared with other Small Advanced Economies and Australia. BERD has increased significantly in nominal (+84 per cent) and real terms (+42 per cent) between 2004 and 2014#. As a proportion of GDP it has increased from 0.47 per cent to 0.54 per cent over the same period.

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

\# Note that because of changes in survey methodology, it is not valid to compare results from 2004 and subsequent periods with prior years. A further change to the R&D survey was made in 2012, although the resulting change in absolute value of R&D reported was small (based on restatement of 2010 figure to match new methodology).

Figure 14 Business expenditure on R&D as a proportion of GDP

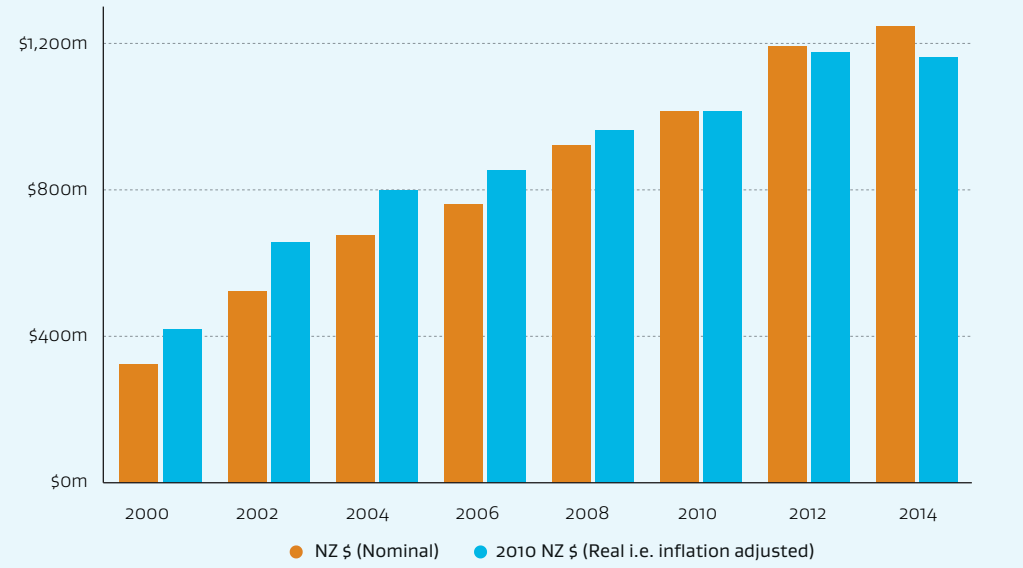


High R&D expenditure in 2012 was driven by the behaviour of primary firms and food and beverage firms. Specifically, Solid Energy invested in R&D in 2012, but not in 2010 or 2014 and there were also one-off capital investments by food and beverage firms in 2012.

The government increased support and co-funding for business R&D with the creation of Callaghan Innovation in 2013. This included introducing R&D Growth Grants, which are designed to incentivise business R&D by providing government co-funding at a rate of 20 per cent. It is too early to see any impact from this policy in the R&D survey results.

The data available for 2015 (not shown in Figure 15) suggest that business R&D grew strongly to $1.44bn and 0.60 per cent of GDP in 2015, compared with $1.25bn and 0.54 per cent GDP in 2014. This data point is from a different source (Business Operations Survey) to Figure 15 (R&D Survey) and is not strictly comparable due to different sampling methodologies. MBIE is developing an annual measure of Business R&D which will be used in future reports.

Figure 15 Business expenditure on R&D, nominal and real (inflation-adjusted)



COMPANIES WITH SALES FROM PRODUCT INNOVATIONS

What it measures

The measures the proportion of businesses that have reported sales from innovation in the Statistics New Zealand Business Operations Survey.

Why it matters

A key role of the innovation system is to develop new and innovative services and products. This, in turn, leads to higher incomes, greater productivity, and improved exports. A robust measure of successful innovation is new products reaching market. Businesses with sales from innovation is an indicator of successful innovation. It excludes other important types of innovation such as business process improvements which could result in cost-savings or higher added value.

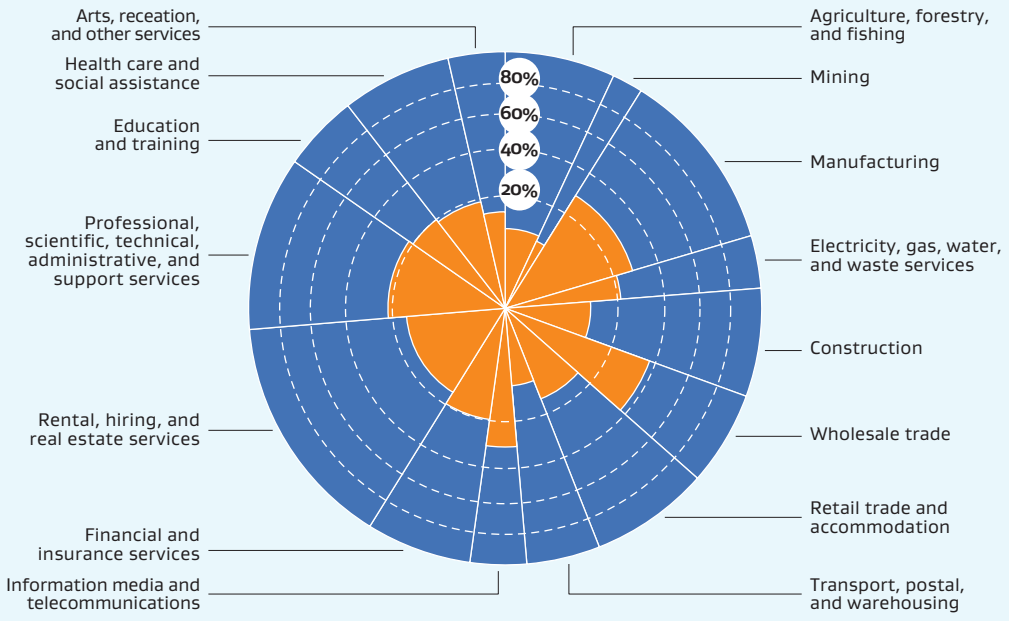
What the data show

18.1 per cent of businesses reported sales from innovation in 2015, up from 17.0 per cent in 2013. The radial diagram combines innovation rate by industry sector with each sector's share of the economy in 2015.

The 2015 data show that manufacturing, which accounts for 14 per cent of GDP, also reports high numbers of firms with sales from innovation. Information, media and telecommunications reports the highest rate of firms with sales from innovation, at 36 per cent. However, it accounts for a comparatively low share of GDP (3 per cent).

Wholesale trade reports the highest levels of sales from new products. It is not clear if this represents new products developed by firms which are both manufacturers and wholesale traders, or if this is new products developed outside New Zealand and wholesaled here for the first time.

Figure 16 Proportion of businesses reporting innovation (extent of orange area from centre) and their sector's share of the economy (angular width of pie-slice), 2015



Focus on Business R&D Expenditure

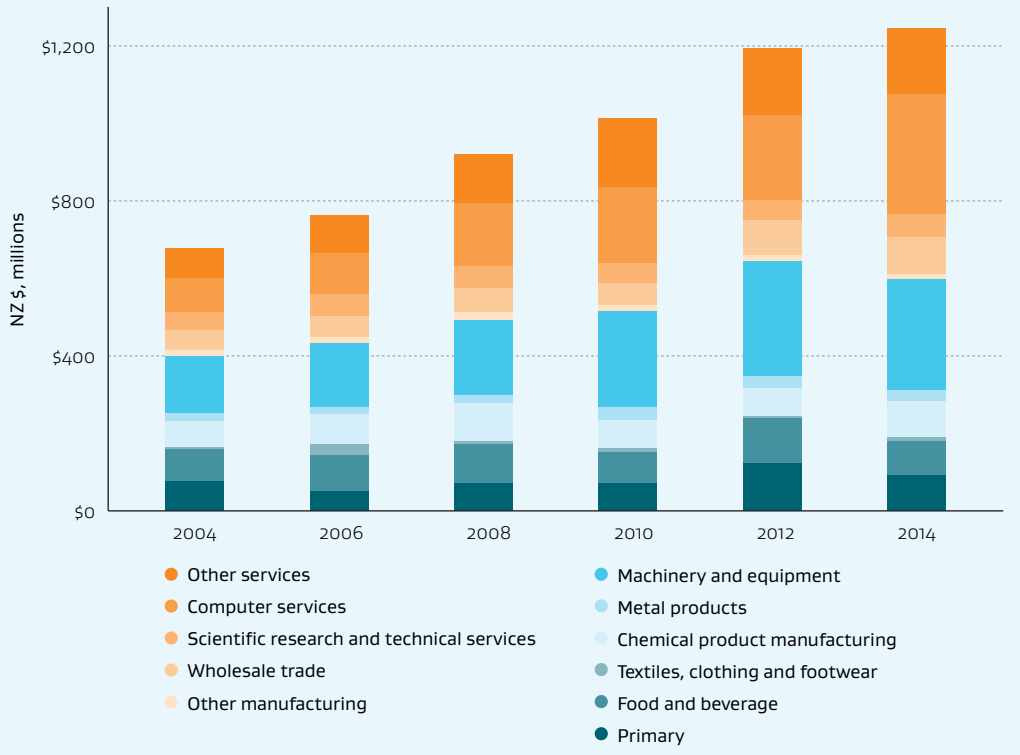
Drilling into the business R&D (BERD) data helps explain why New Zealand's BERD trails the OECD and the other Small Advanced Economies in this area, and suggests opportunities for growth.

R&D EXPENDITURE BY INDUSTRY

This shows how business R&D expenditure is split across industries and which industries are driving growth.

What the data show

Figure 17 R&D expenditure by industry sector



The computer services and machinery and equipment industries have been important contributors to BERD growth in recent years.

Note that the methodology used to collect these data changed in 2012, so comparisons between 2012 and prior years are not completely valid.

International comparison

New Zealand's business R&D differs from other OECD countries both because of our industry structure (the size of different industries) and because of the R&D intensity of each industry (R&D as a proportion of industry GDP).

Previous analysis (based on 2006 data) showed that about half of New Zealand's lower Business R&D intensity is explained by industry structure and about half by New Zealand firms spending less than the OECD average for that industry[3].

Industries with the highest R&D intensities worldwide are: machinery and equipment manufacturing; chemicals, fuels, plastics and pharmaceuticals; and professional, scientific, research and technical services.

These R&D intensive sectors make a smaller contribution to New Zealand's R&D compared to other countries. This is consistent with the fact that New Zealand does not have an automotive industry, and our pharmaceutical companies do not focus on drug discovery.

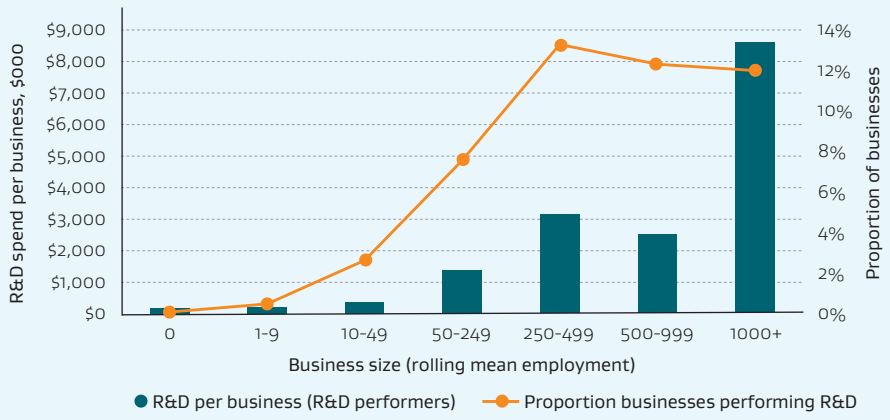
DISTRIBUTION OF BERD BY COMPANY SIZE

This measures how R&D is distributed across different business sizes. The resources needed to undertake large R&D projects and ability to capture a larger share of the benefits of R&D are more prevalent in large businesses.

What the data show

Larger businesses in New Zealand are more likely to undertake R&D, and spend more money on average when they do.

Figure 18 Percentage of businesses who engage in R&D (line) and their average spend (column)



In spite of this, the bulk of the total spend on R&D occurs in businesses that fall in the medium sized business groups (10-49, and 50-249 FTE).

Figure 19 Total R&D spend by businesses in each size bracket

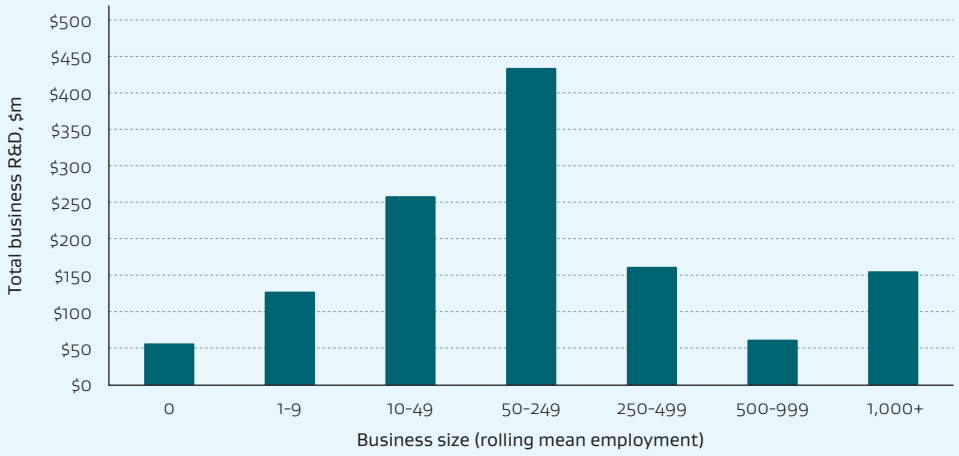


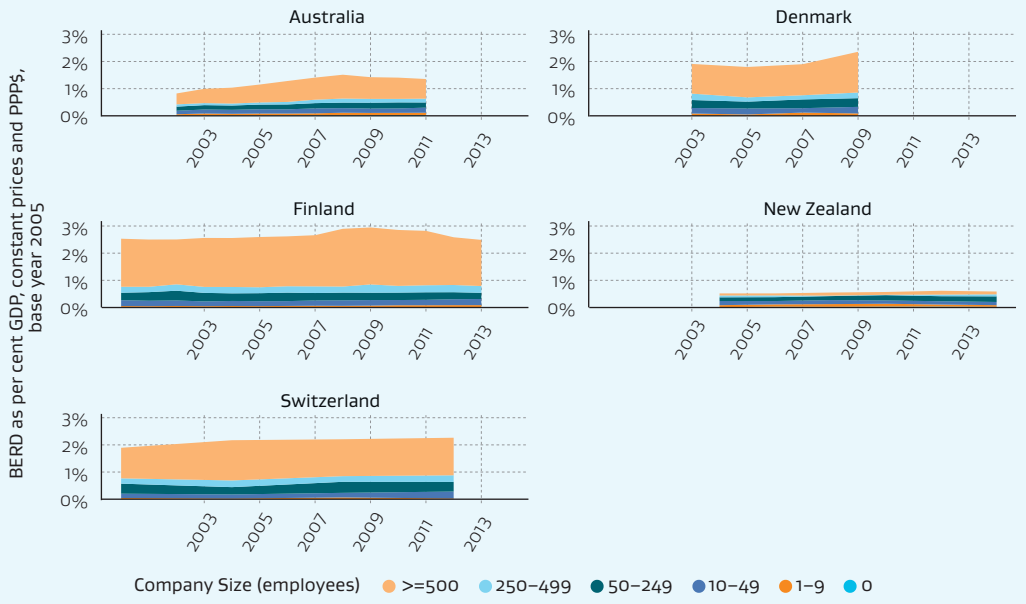
Figure 20 illustrates how the distribution of R&D by business size is dramatically different in other Small Advanced Economies. Companies with more than 500 staff perform 50 per cent or more of the total BERD in Denmark, Finland and Singapore but only 18 per cent in New Zealand. It is lack of R&D in large companies which is driving New Zealand's low overall BERD rates.

New Zealand actually has a similar number of large companies (i.e. with greater than 1000 employees) to Denmark and Finland. However New Zealand lacks the very large, multinational companies which tend to drive R&D expenditure in other countries.

For example, the 10 largest companies listed on the NZX range in value from $1.2b up to $5.3b (USD)*, whereas Denmark's top ten companies range from $1.4b up to $90b. The $90b Danish company is the pharmaceutical multinational Novo Nordisk. Novo Nordisk spends around $2b per year on R&D (around 17 per cent of its revenue). This alone accounts for around one quarter of Denmark's total business R&D expenditure.

New Zealand has two companies with revenue of similar magnitude to Novo Nordisk – Fonterra and Fletcher Building. These companies' R&D expenditure is a fraction of one percent of their revenues. This highlights the profound effect which a country's largest companies can have on overall business R&D.

Figure 20 R&D expenditure as a proportion of GDP, by business size



* Market capitalisation at 10th June 2016.

NUMBER OF TRIADIC PATENT FAMILIES GRANTED

What it measures

Triadic patent families are a set of patents registered at the three major patent offices: the European Patent Office (EPO), the Japan Patent Office (JPO) and the United States Patent and Trademark Office (USPTO). Triadic patent family counts are attributed to the country of residence of the inventor and to the date when the patent was first registered. The "triadic patent families per million people" measure allows us to normalise and compare patent outputs across countries.

Why it matters

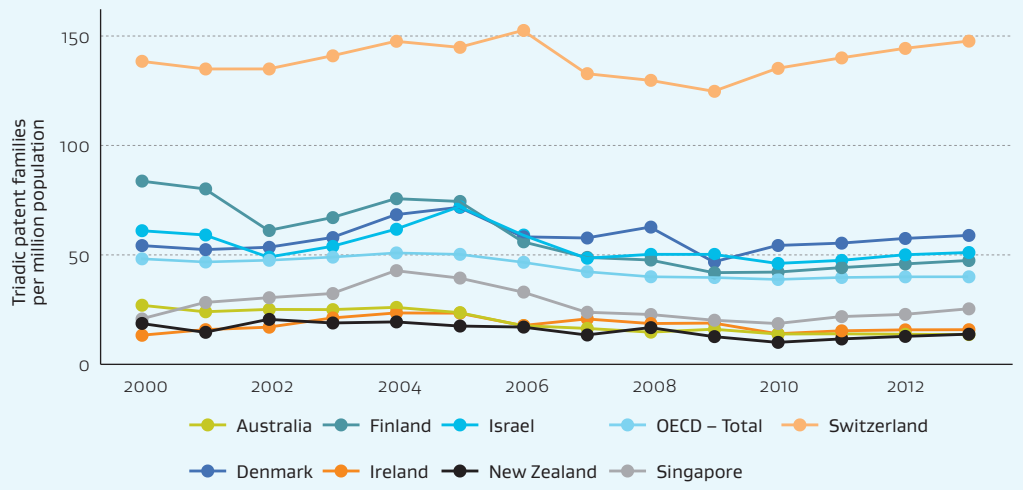
The output of patents is an accepted proxy measure for innovative activity and provides for comparison across countries on how active a country is at producing patentable outputs. As with all proxy measures, there are some important caveats to bear in mind.

The country of residence of the first name on the patent application form is used, so it is important to look at the results in conjunction with measures of collaboration on research. In addition to this, not all patents lead to commercially successful products.

What the data show

New Zealand's rate of patents per million people is similar to Australia, but low compared to most Small Advanced Economies and the OECD average. New Zealand's patenting rate has been relatively consistent and we haven't seen the significant drop that Finland, Singapore, Denmark and Israel have over the last ten years, but we have seen a small, but consistent increase since 2010 that runs counter to the constant OECD average over that same period.

Figure 21 Triadic patent families granted per million population



RESEARCH PUBLICATIONS WHICH ARE CITED BY PATENTS

What it measures

This measures citations made by patent applications to scholarly articles. As citation measures tend to trend down the closer you get to the current date, these values are adjusted as a percentage of the OECD average for that year.

Why it matters

This is a proxy measure for how often a country's research results in innovation somewhere in the world.

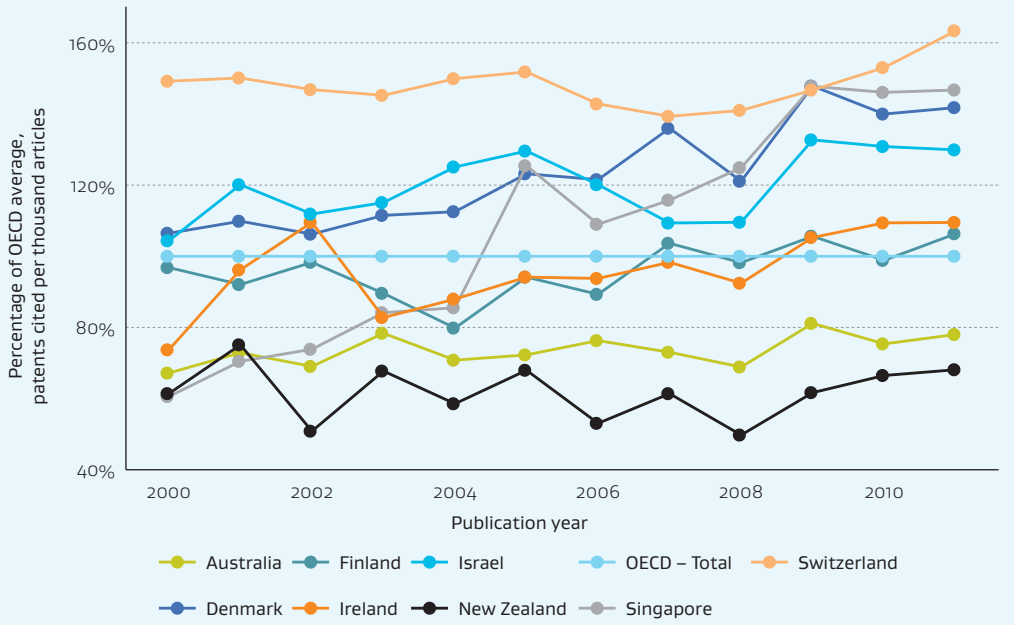
There are some caveats to how much can be inferred from this measure:

- The five largest patent offices included in this measure account for approximately 50 per cent of patents.
- The data includes all patents independent of their status (application, grant or rejected).
- There is an approximately 18 month lag in the data due to patent processing times.
- If research findings are sufficiently similar to a patentable invention then a researcher seeking to protect this intellectual property will normally patent before publishing. In this case the link between the research publication and patent would not be picked up by this measure.

What the data show

New Zealand tends to sit below the OECD average, Australia and the Small Advanced Economies. This has been relatively consistent since 2000. The noisy nature of the data is also indicative of there being a small pool patents and articles, and as a result, small changes can have disproportionate impacts.

Figure 22 Proportion of research outputs which are cited by patents



Impacts

Impacts refer to beneficial changes in economic, health, social or cultural outcomes to which science and innovation have contributed. These outcomes are constantly changing, for a whole number of reasons, including science and innovation. In addition, impacts generally don't flow from science and innovation in a simple, linear way. Impacts may result from discoveries made in New Zealand or overseas, recently or years previously, and directly or indirectly from people applying skills and knowledge they have developed through scientific research.

Currently, we are unable to present a systematic picture of the impact of public research in New Zealand. The few studies that have addressed the impact of public research in New Zealand present a mixed picture. CRIs and universities provide many examples of individual innovations making a difference. However, assessment of these benefits requires some form of aggregation that needs to take into account the different dimensions of impacts. The starting point for this analysis is to develop a reliable set of longitudinal data. Assembling this dataset is one of the aims of the *Science and Innovation Domain Plan*.

Approaches to measuring impact include indicators, impact case studies, cost-benefit analysis and econometric analysis. This report uses one impact indicator (economic complexity) and impact case studies.

Future reports will use a range of approaches including more robust sampling and preparation of case studies. This will be combined with better science funding administration data and tracking of researchers over time to improve the attribution of impacts to science investments and policies.

IMPACT INDICATOR: ECONOMIC COMPLEXITY RANKING

What it measures

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. The rank here is important because the economic complexity of our exports is only measurable in relation to other countries. More complex products (like sophisticated chemicals and machinery) require more knowledge and a skilled workforce to manufacture. The more complex a product, the fewer countries are likely to have all the required knowledge and skills to produce it.

The economic complexity index is calculated from international trade data. The complexity of a product (and the economy producing it) is inferred from how many other products are consistently co-produced with it – complex products are associated with a whole-range of other upstream and downstream products in the domestic value-chain.

Why it matters

Economic complexity provides a useful link between the science and innovation system and its economic impacts. The science and innovation system will provide some of the skills and knowledge required for firms to move into more complex products.

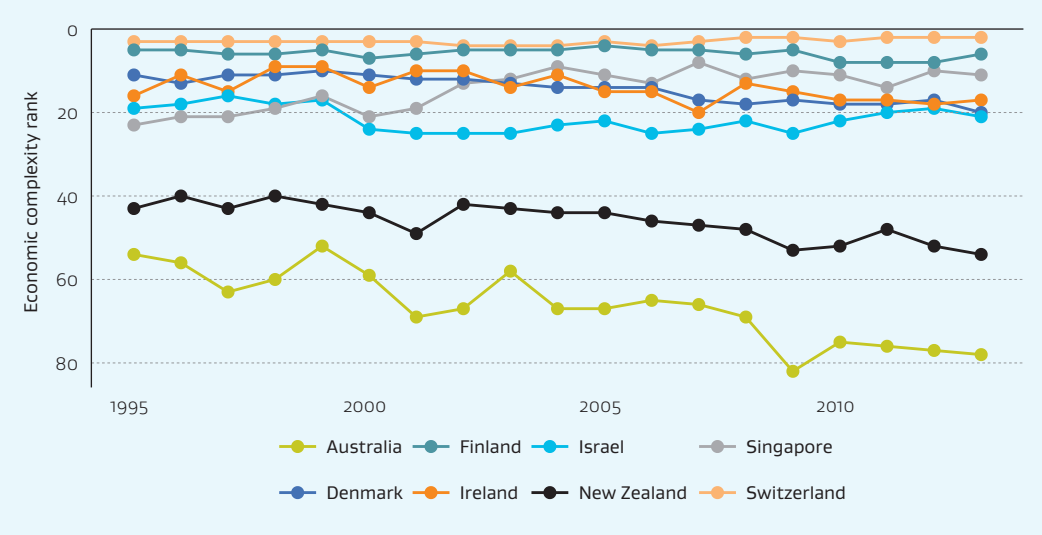
More economically complex countries (by this measure) have been shown to be more economically developed or on the cusp of rapid economic growth.

What the data show

New Zealand performs poorly compared with other Small Advanced Economies, and ranks 54th overall in the economic complexity world ranking. Our place in this ranking has deteriorated over time.

Other significant commodity exporters also tend to perform poorly on this measure (e.g. Australia ranked 78th in 2013). That could be because this measure is likely to understate complexity in products which is not directly embodied in the products themselves. For example, an exported New Zealand apple may be the result of significant R&D investment in breeding programmes, harvesting technology and environmental management. Such investment will have improved productivity and volume of exports, but will not necessarily result in a more complex product. Future reports may probe this economic complexity measurement issue in more depth.

Figure 23 Economic complexity – position in world ranking



Southern Hemisphere Influenza and Vaccine Effectiveness Research and Surveillance (SHIVERS)

Influenza ('the flu') and respiratory illnesses have a huge impact on the health and wellbeing of New Zealand families. Influenza can pose a serious health risk and can be fatal to young children and the elderly. The reach of influenza can be global as was the 1918 Spanish Flu pandemic that infected an estimated 500 million people and killed up to 3-5 per cent of the world's population.

Illustration of Influenza Virus H1N1. Swine Flu

Understanding influenza is critical to minimising its risks to human health. Every year, the World Health Organisation (WHO) gathers information about circulating influenza virus strains, which is used in the selection of flu virus strains for the next season's vaccines. The WHO Global Influenza Programme coordinates the collection and analysis of this influenza surveillance data from around the world, according to common standards.

The aims of the Southern Hemisphere Influenza and Vaccine Effectiveness Research and Surveillance (SHIVERS) project are to understand how the influenza virus spreads, mutates, and interacts with other harmful viruses in New Zealand. SHIVERS contributes to WHO's Global Influenza Programme and New Zealand's vaccination policy. The Institute of Environmental Science and Research (known as ESR) leads the project in a multi-agency collaboration with the University of Auckland, Auckland District Health Board, Counties Manukau District Health Board, the University of Otago, and two United States agencies: St Jude's Research Hospital; and the Centers for Disease Control and Prevention (CDC).

ESR was selected by the CDC for the $10m project over all other applicants. This was due, in-part, to a 'smart' study design that was able to address many questions, and a strong research team drawing skills, knowledge and experience from multiple institutions.

SHIVERS builds upon the numerous strengths of the New Zealand's healthcare system. SHIVERS researchers can easily collect and link data from the electronic data management systems of local general practices, hospitals, and laboratories with the patient national health index number (NHI number).

SHIVERS gathers data from patients with respiratory illness at hospitals and 16 'sentinel' general practices in the Auckland region. Patients are tested for the presence of influenza and non-flu respiratory viruses. Counts and other routine analysis is published on ESR's website weekly during the winter. Every year, SHIVERS researchers assess the effectiveness of the current flu vaccine. The vaccine has ranged from 40-76 per cent effective at preventing influenza over the study years, which is expected based on the match between the circulating influenza virus and the vaccine.

The SHIVERS project has collected a huge library of epidemiological* data on influenza. This provides insight into influenza's impact in the community: prevalence across different demographic groups, co-occurrence with other illnesses, outcomes for patients in general and for people who have higher risk factors.

For example, SHIVERS has shown that pregnant woman were five time times more likely to be hospitalised as a result of influenza than non-pregnant woman. It also found that high numbers of young children in New Zealand tested positive for influenza and other viruses including

* Epidemiology is the study of the incidence, distribution, and possible control of diseases and other factors relating to health.

respiratory syncytial virus (RSV). Findings from SHIVERS have led to changes in the New Zealand's vaccination policy for children. The Ministry of Health has used SHIVERS data to monitor for infections emerging outside of New Zealand including Middle East Respiratory Syndrome coronavirus in 2012 and bird flu 2013.

In 2015, the project introduced what is known as a serological survey to understand the immunity and protection that people in the community have against influenza. This serological survey, one of the largest and most comprehensive to date globally, enrolled 2500 people. During the winter flu season, randomly selected participants were monitored for cold or flu symptoms and tested for the presence of viruses. Among participants not vaccinated for influenza, about one in five were infected with influenza, and the rate was even higher for children younger than 19 years old (one in three). Over 70 per cent of those infected with influenza did not have classical flu symptoms. And of those with symptoms, 80 per cent did not seek care. The finding is important for thinking about how to prevent the spread of flu with means like case isolation or social distancing. SHIVERS researchers will also use findings from this study to look for ways to better predict the impact of influenza.

SHIVERS has helped to inform WHO decision-making regarding global influenza surveillance and vaccination policy. Annually, WHO uses SHIVERS data when considering changes to the seasonal influenza vaccine. In 2012, WHO changed the severe acute respiratory illness (SARI) case definition based on SHIVERS findings. This definition is used worldwide to identify the hospitalised patients with the greatest chances of having influenza and to compare trends in severe influenza disease across countries and over time. Based on SHIVERS findings, WHO increased the time allowed in the SARI case definition for hospitalisation from within seven days of onset to within 10 days of onset.

The project funding from the CDC will end this year, in 2016. The Ministry of Health has also provided funding since 2014, and has committed to continue funding for the programme.

Soil mapping: S-Map

The Government has set priorities of growing exports and ensuring responsible management of New Zealand's freshwater resources through the Business Growth Agenda, the Ministry for the Environment's National Policy Statement (NPS) for Freshwater Management, and the Freshwater Reform Programme.

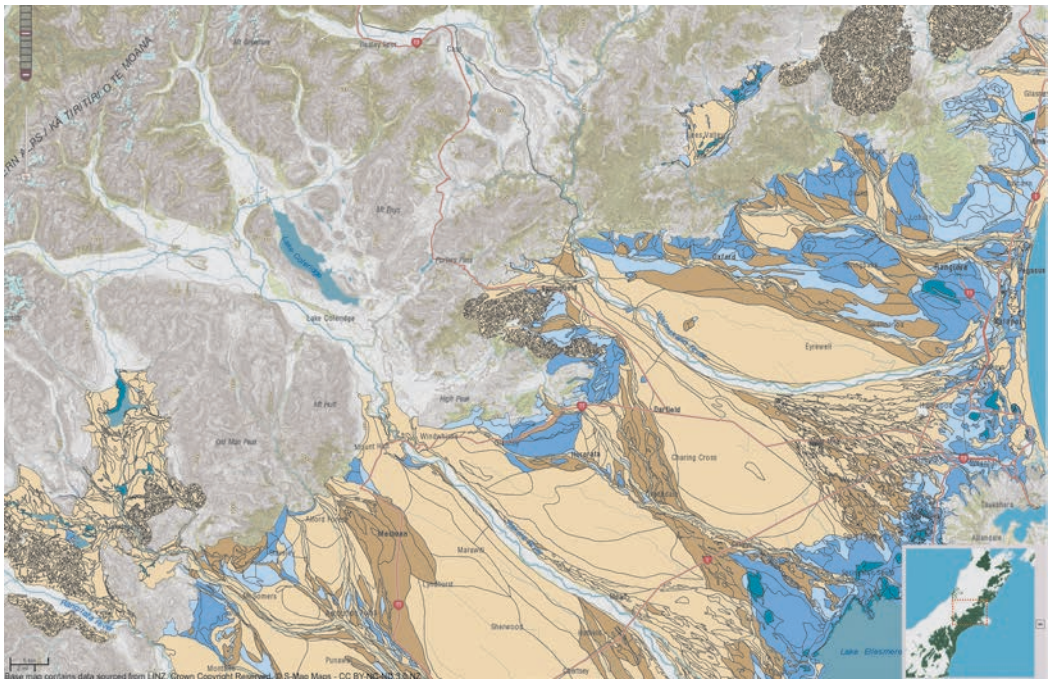


Image supplied by: Landcare Research. http://smap.landcarere-search.co.nz

Agriculture, horticulture and forestry are fundamental to meeting export goals but farming activities can result in 'runoff' of bacteria, nutrients and contaminants into waterways. Soil plays a critical role in buffering and filtering runoff while supporting crop growth. Soil properties are critical to finding solutions that improve productivity and water-use efficiency, and reduce nutrient leaching.

Information on New Zealand's soil allows us to tune land management to their unique qualities. Armed with accurate and accessible soil information, farmers and central and local government officials can make informed resource management policy, and land and water management decisions.

Over the past decade, Landcare Research has been developing an online tool called S-Map to provide good soil information across New Zealand. With 4,528 unique soil types in New Zealand, S-Map helps to show which soil types occur where and their underlying soil properties.

S-Map is built from a combination of 'point' field-measurements, laboratory analysis of chemical and physical properties, and extrapolated data. Field measurements are time-consuming and require expert knowledge, but point data can be used to extrapolate across the entire landscape by interpreting factors that affect soil formation such as climate, bed rock and geological processes. This has allowed S-Map coverage to expand to 28 per cent of New Zealand's total land mass, and 58 per cent of the most intensive primary sector areas.

In addition Landcare scientists have developed 'digital soil mapping' techniques to predict data on the 'functional properties' of soil, which are particularly difficult to measure. This includes water retention properties, which are highly relevant to decisions on land use, management and irrigation regimes, and nutrient budgeting.

S-Map allows land uses and nutrient management decisions to be tailored to the properties of a particular soil type. This means agricultural production can be more cost-effectively managed within environmental limits. For example, 'leaky' soils are less effective at filtering out and utilising nitrogen, which results in more nitrogen entering waterways, a leading cause of algal bloom. Soil map data allows farmers to target their mitigation techniques to these areas to minimise nitrogen leaching. A study by Landcare research in the Southland catchments of Mataura and Oreti estimated a 6:1 benefit-cost ratio within a year, when soil map data were used to target leaching-mitigation strategies to leaky soils.

S-Map data has underpinned a variety of policy and management decisions, including the evidence which supported Cabinet policy

* https://www.mfe.govt.nz/sites/default/files/modelling-economic-impacts-of-nutrient-allocation-policies-canterbury.pdf

decisions on freshwater reform and the NPS for Freshwater Management. For example the Hinds catchment case study, commissioned by the Ministry for the Environment, estimated the economic costs of reducing nitrogen leaching through a range of mitigation practices*. Soil data were critical to predicting what nitrogen leaching practices were appropriate and how effective they would be on which land areas.

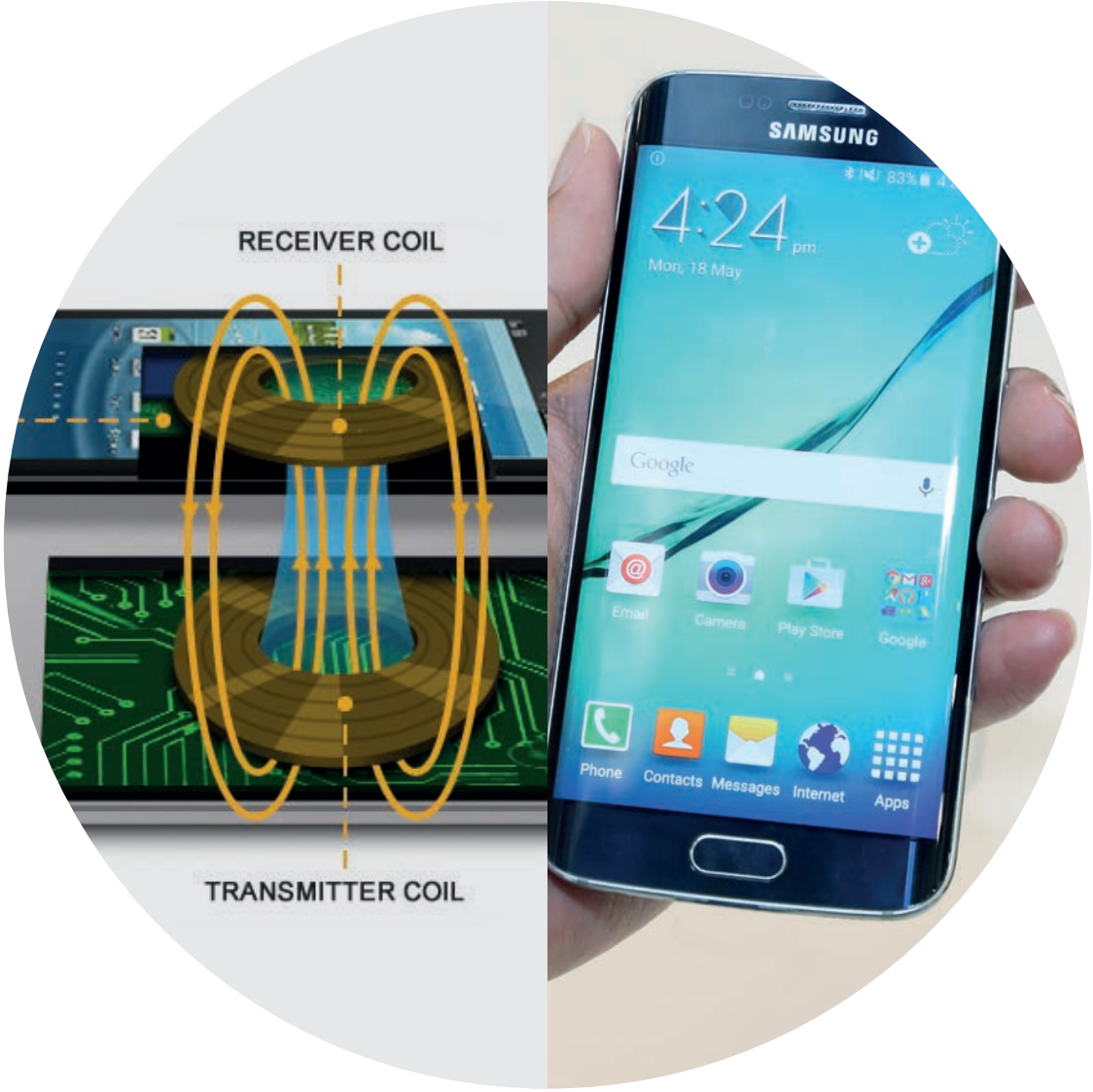
At the regional level, S-Map data has been used to support decision-making including by Environment Canterbury to develop the Canterbury Land and Water Regional Plan, and by Waikato Regional Council to set nutrient discharge allowances in the Rotorua Te Arawa Lakes area.

At the farm-level, S-Map data for soil properties that control nutrient leaching is now automatically incorporated within the OVERSEER® nutrient budgeting tool. OVERSEER is a software tool that models nutrient cycling in a farm system to help farmers make nutrient budgets. It relies on accurate soil information in order to produce reliable results.

The use of S-Map by land managers and consultants, regional and central government, and scientists is increasing. In the 5 years since its launch, S-map Online has had over 150,000 unique visitors, with visitor numbers increasing by an average of 42 per cent per annum.

Landcare Research successfully bid for $9.3m of new funding in the 2016 Endeavour round for science to underpin the next generation of S-map and smarter land management decisions.

Wireless charging: PowerbyProxi and Halo IPT



The dream of wireless transfer of power has existed since the origins of our modern understanding of physics and electrical engineering. Wireless power transfer removes the physical constraint of a cable. This opens the potential to 'beam' power to moving or rotating objects or machine parts. Without a cable, there are no exposed electrical contacts to be waterproofed, meaning safer and more convenient power in dirty, wet outdoor and industrial environments.

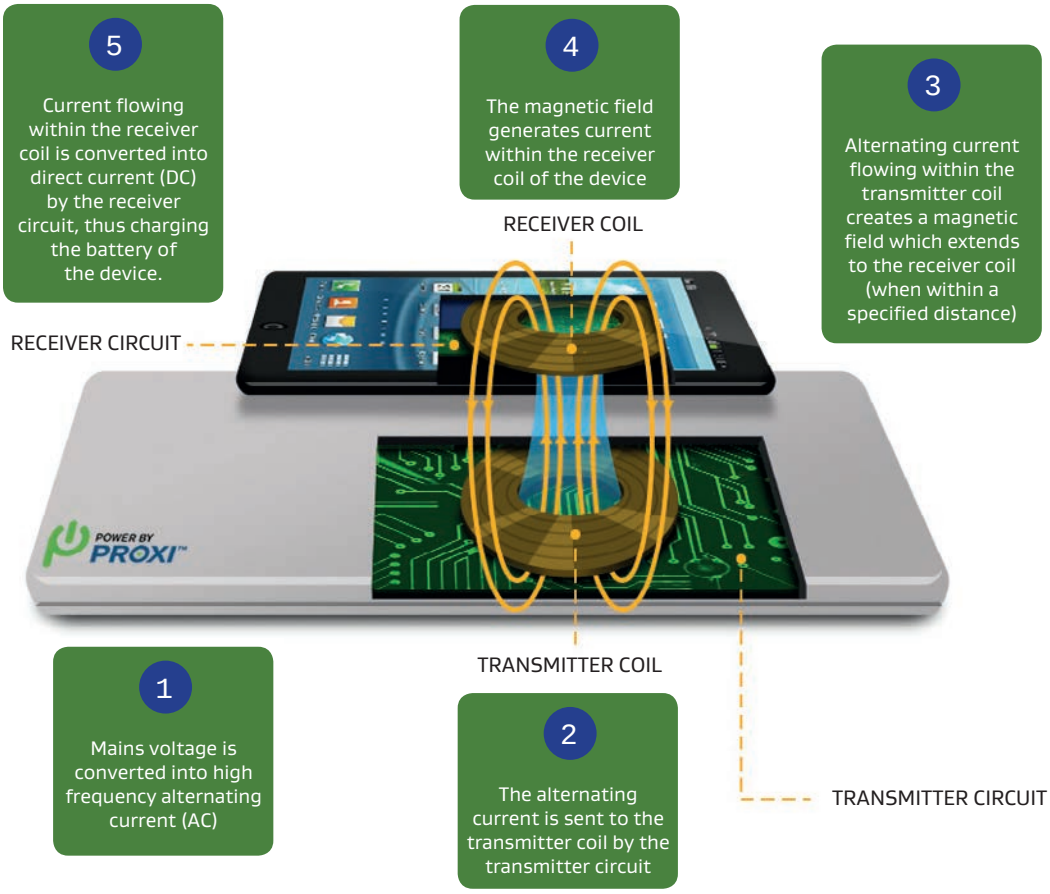


Image supplied by: PowerbyProxi

The basic physics behind wireless power transfer has been known for over a hundred years. Hertz showed information could be transmitted between electric circuits using radio waves, leading to the development of modern radio systems. Faraday discovered electromagnetic induction – demonstrating the transfer of energy between electric circuits via magnetic fields. Nikola Tesla built upon Faraday's work with the invention of the induction motor.

In spite of these fundamental discoveries, it was believed for over a hundred years that useful wireless power transfer over large distances was not practically-possible. The practical challenges were creating a set-up which could tolerate misalignment and large gaps between the power receiver and transmitter. Research performed by John Boys and colleagues at the University of Auckland by in 1991 proved this belief wrong.

The research produced what is known as an inductive power transfer (IPT) system capable of efficiently transferring significant power between a transmitter and a receiver. A key invention was so-called 'dynamic tuning' of the receiver circuit. This meant that devices receiving power were resonating in-phase with the transmitter, which ensures higher efficiency of power transfer. This approach also allowed several receiving devices to be simultaneously connected to a single transmitter.

The IPT technology was licensed globally for materials handling and mass-transport applications, and to a New Zealand lighting company. Recognising the potential of the technology, the University of Auckland established a research programme and a lab to support further development and application of wireless charging through IPT systems.

This technology has led to two spinout companies though Auckland Uniservices Limited (the University commercialisation company).

Funding of $600,000 was provided in 2004 for further research and development – $400,000 from Auckland Uniservices and $200,000 from the Pre-Seed Accelerator Fund. The objective was to develop wireless power charging technology for laboratory equipment and consumer goods such as smartphones, watches and appliances.

As a result, PowerbyProxi was spun-out in 2007 as a wireless technology design house using the licensed technology. The company has built more

than 50 wireless power applications for Fortune 500 companies, and has a comprehensive portfolio of 333 patent rights worldwide. The company's technology was also chosen as the standard for 'wide-gap resonant wireless charging' for consumer electronic devices by the wireless power consortium. PowerbyProxi now employs over 80 staff and is based in Auckland.

In 2007, Auckland Uniservices identified further opportunities for research and development for wireless power technology applications in the emerging electric vehicle market. Wireless charging has the potential to greatly extend the range and ease of use of electric vehicles. It allows electric vehicles to be charged wirelessly while parked, or even while driving via transmitters embedded in the tarmac.

The technical challenge in this area is to transmit power over the relatively wide gap between the bottom of a vehicle and the IPT charger. 250-300mm is the normal clearance of road vehicles, whereas existing technology was only effective over a few millimetres. The solution also needed to keep magnetic field strength within the limit allowed by regulation.

In 2009 the Pre-Seed Accelerator Fund provided $450,000 of funding for R&D in this area, which was matched by Uniservices. This funding enabled the development of technology that would reliably and efficiently transfer power over the gap between the road and the bottom of the vehicle.

The success of this R&D led to the spin-out of Halo IPT, whose objective was to develop world-leading wireless power charging technology for transport applications. Halo IPT was purchased by Qualcomm in 2011, which enabled the technology to be taken to the world market. Following the purchase of Halo IPT, Qualcomm set up one of its electric vehicle R&D centres in New Zealand, employing eight staff. Auckland UniServices continues to receive royalties related to the IP generated by PSAF investment as well as retaining other multi-million dollar research contracts.

Deep Fault Drilling

The Alpine Fault runs 660km up the spine of the South Island and is the 'on-land' boundary of the Pacific and Australian tectonic plates. The Pacific plate is being rapidly pushed up by the Australian plate along the Alpine Fault, which has formed the Southern Alps.

Satellite image supplied by NASA

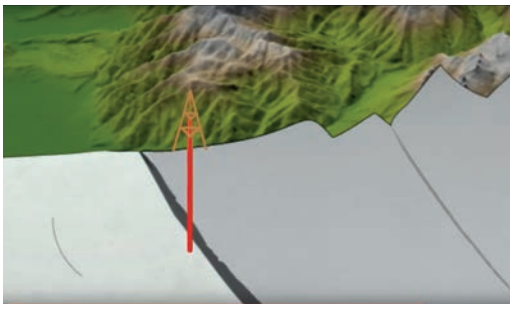


Image supplied by: GNS Science

New Zealand's Alpine Fault is a site of global importance for studying geological faults that will generate large earthquakes. Unlike faults elsewhere in the world that have been investigated by drilling, the Alpine Fault has not produced large earthquakes recently, but has a relatively high chance of earthquake rupture in future. The goal of the Deep Fault Drilling Project is to go beneath the surface to sample and make observations of rocks and physical conditions at a range of depths, and monitor these over the coming decades.

GNS Science was the lead agency in a project to drill into the Alpine Fault. Most measurement of faults and earthquakes are normally done by geologists at the surface. By putting permanent underground measuring devices in during the drilling, scientists are able to cross-reference between measurements taken at the surface and closer to the fault line during quakes. This means that in future these measurements can be used to better infer the processes taking place underground. This greater understanding can be applied elsewhere to improve the understanding of earthquake processes.

A compelling reason to investigate the Alpine Fault is that it is at the end of its earthquake 'cycle' and another large quake is predicted soon, so the new underground instruments put in place will provide a continuous collection of chemical and physical data around the fault line in the years leading up to the next large fault rupture. Geologists will learn in unprecedented detail about the changes in conditions that take place during this period. Such information could ultimately lead to the 'holy grail': earthquake prediction.

The Marsden Fund and the International Continental Scientific Drilling Program were the primary investors in the project. Other financial support was provided by Victoria University of Wellington, the University of Auckland, the University of Otago, the Ministry of Business, Innovation, and Employment. Overseas support was received from the National Science Foundation in the United States.

In the first phase of the project two boreholes were drilled at Gaunt Creek, a tributary of the Waitangitaona River near the Franz Josef Glacier. Continuous rock samples were taken and a subterranean fault-zone 'observatory' was installed in the borehole for long-term monitoring of the fault zone.

In the second phase researchers attempted to drill a 1 km-deep borehole across the fault boundary itself. This phase involved more than 120 scientists from 12 countries.

Drilling boreholes through rock is a very slow process. Drilling for phase two took six months, and managed to reach a depth of 893 metres. Unfortunately the drill case broke at this point and the drilling had to be stopped short of the fault boundary itself. This meant that samples were not able to be taken above and below the fault.

The drilling enabled some significant observations to be made. For example, the thermal gradient (the rate of temperature change with depth) was very high and exceeded 140°C/km in the upper section of the borehole. These temperatures are caused by friction. Friction laws specify how the strength of faults depend on the pressure across them, and knowing the stress needed to overcome rupture resistance allows scientists to understand the failure criteria for the fault.

GNS Science monitors data from the observatory installed in the borehole. There are future survey plans for the fault, and it is hoped to restart the project in future to complete all of its objectives, specifically drilling through the fault boundary itself.

Clover root weevil

New Zealand is an internationally competitive producer of pastoral agricultural products such as dairy, wool and meat. This is partly due to its low-cost pastoral farming systems, which provide cheap, high quality animal feed year-round from high-producing grass and clover varieties in a favourable climate. Clover is critical to this success because it is highly nutritious for livestock and because it can capture or 'fix' nitrogen from the atmosphere.

Clover root weevil (Sitona obsoletes).
Walker, K. (2007). http://www.padil.gov.au.

Nitrogen is a key nutrient required in plant growth. Although it is plentiful in the atmosphere, plants cannot absorb it directly from the air and rely on it being present in the soil in an absorbable chemical form. Nitrogen can be supplied in the soil by applying fertiliser. However, clover plants can convert atmospheric nitrogen into absorbable soil nutrients, which later become available to other pasture plants from decomposing clover plants and animal urine and manure.

New Zealand's farming systems rely on a limited range of introduced pasture species, including clover, which leaves the agricultural sector vulnerable to the many invasive pests and diseases that target these species. Clover root weevil is an invasive pest from the northern hemisphere which eats clover, and was first detected in New Zealand in 1996.

Clover root weevil reduces feed quality, soil nitrogen content, and ultimately farm profitability. Although its damage can be mitigated by applying more nitrogen fertiliser, this incurs additional costs, which limits this option to intensive systems, and may result in higher nutrient run-off into waterways and higher greenhouse gas emissions (in the form of nitrous oxide). This severely threatens the competitiveness of New Zealand's pastoral systems: a 2005 study estimated that without control, the weevil could cut farm margins by 10 per cent to 15 per cent.

By the time it was detected, clover root weevil was already widespread over more than 200,000 hectares of the North Island. It spread readily in New Zealand because of a lack of natural enemies, abundant clover, minimal competition from other species, a favourable climate, and because it is a highly mobile species. This meant that the only effective option for widespread suppression of the weevil was what is known as a 'biological control'.

AgResearch started an R&D programme in 1996, which aimed to mitigate the impact of clover root weevil on New Zealand's pastoral industries. It collaborated with European and United States agencies to identify natural enemies of clover root weevil in the northern hemisphere that could be considered for use as biological control agents in New Zealand. The researchers found several insects that parasitise and kill clover root weevil, and chose one for further assessment. It was imported from Ireland into quarantine at AgResearch to test what other organisms it could potentially parasitise in New Zealand if it was released. The researchers wanted to be sure the Irish wasp would not harm any New Zealand

Adult clover root weevil

beneficial or native organisms. The testing showed this 'Irish wasp' is specialised only to parasitise clover root weevil and its close relatives, and was a negligible risk to other New Zealand organisms. Permission was obtained from the Environmental Risk Management Authority, under the Hazardous Substances and New Organisms Act, to release it in 2005.

The Irish wasp parasitises clover root weevil by injecting eggs into the adult weevil. The eggs grow into grubs which feed inside the still-living weevil rendering it infertile. Once fully grown, the parasite grubs eat their way out of the weevil to pupate in the soil, and the weevil dies. Once the pupae have developed into adult wasps the cycle begins again. One Irish wasp can kill about 85 clover root weevils.

In 2006, AgResearch made six initial experimental releases of the Irish wasp in various North Island locations, and found that it immediately flourished and began to suppress clover root weevil populations at all release locations. In the same year, clover root weevil was discovered in the South Island for the first time and the Irish wasp was released there too, where it also flourished. Based on these extraordinarily positive results, AgResearch began a multi-agency nationwide programme to release the Irish wasp in all New Zealand areas where clover root weevil was present.

The Irish wasp spread from its release locations at about 20km per year, mainly as eggs and grubs within adult clover root weevils, which can fly well. AgResearch tracked the spread of clover root weevil and the Irish wasp in New Zealand and made additional releases as required to ensure all affected farmers would benefit from the biological control programme as quickly as possible. It developed a computer model to prioritise locations for Irish wasp releases. Farmers also obtained Irish wasps from AgResearch through industry consultancy

networks, and at field days and meetings to release themselves. The Irish wasp would usually parasitise more than 75 per cent of clover root weevils at a location within 2-3 years of arriving there, which reduced weevil populations by around 90 per cent.

The main funding sources for the project were the pastoral industry (approximately $3.9m), the Foundation of Research, Science and Technology* (approximately $2.6m), and AgResearch (approximately $0.8m). Smaller research funders such as AGMARDT and the C. Alma Baker Trust also contributed. Comprehensive support from the agricultural industry aided success and uptake of this project's outcomes. For example, many farmers actively sought to obtain the Irish wasp from AgResearch, which always obliged, and made their properties available for sampling weevils and conducting trials. There has been considerable involvement in the response to clover root weevil from industry bodies including DairyNZ, Beef+Lamb NZ, fertiliser companies, Federated Farmers, the Clover Root Weevil Action group, and the New Zealand Landcare Trust.

AgResearch has estimated the total benefits of the biological control programme from 2006 to 2016 to be at least $489m. Benefits will continue to accrue at the rate of at least $158m per year. This is based on reduced production losses on sheep and beef farms, and reduced use of urea fertiliser to compensate for clover root weevil damage on dairy farms. Compared with R&D costs to date of approximately $8.2m, this gives a benefit:cost ratio of 61:1. This is an underestimate because it excludes pasture quality benefits, benefits to other sectors such as deer, equine and bee-keeping, and the impacts of fertiliser use on the environment and New Zealand's global marketing brand.

* now part of the Ministry of Business, Innovation and Employment

Section 2:

Inputs

Funding

The data in this section show how much is invested in 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.

TOTAL R&D EXPENDITURE (OR GERD – GROSS EXPENDITURE ON R&D)

What it measures

This measures expenditure on Research and Development (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*".

Why it matters

R&D intensity (R&D as a proportion of GDP) is an indicator of the share of the economy's productive 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.

What the data show

New Zealand's R&D expenditure was 1.2 per cent of GDP in 2014. New Zealand devotes a smaller share of its economic resources to R&D activity than other Small Advanced Economies (Finland, Denmark, Ireland, Israel, Singapore and Switzerland), Australia and the OECD average.

New Zealand's expenditure on R&D grew by nearly 2.5 times between 2000 and 2014. Inflation-adjusted expenditure grew by 75 per cent over this period, with a slight drop between 2012 and 2014*. Expenditure grew at around the same rate as GDP, so that R&D expenditure as a proportion of GDP has remained fairly constant.

A change in GERD/GDP can be seen across all the Small Advanced Economies after 2008, which is related to the Global Financial Crisis. The Global Financial Crisis affected both GDP and R&D expenditure as governments reacted to the crisis with public spending adjustments.

* The adjustment for inflation uses the GDP implicit price deflator, which adjusts for the change in prices of all economic outputs. International research suggests that this underestimates the rate of inflation of R&D costs.

Figure 24 Total expenditure on R&D as a proportion of GDP

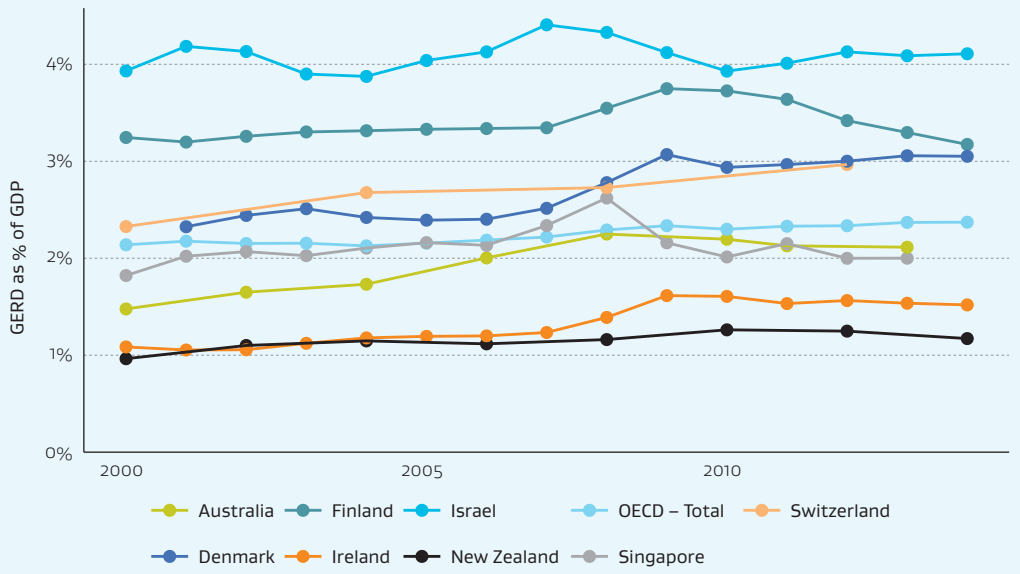
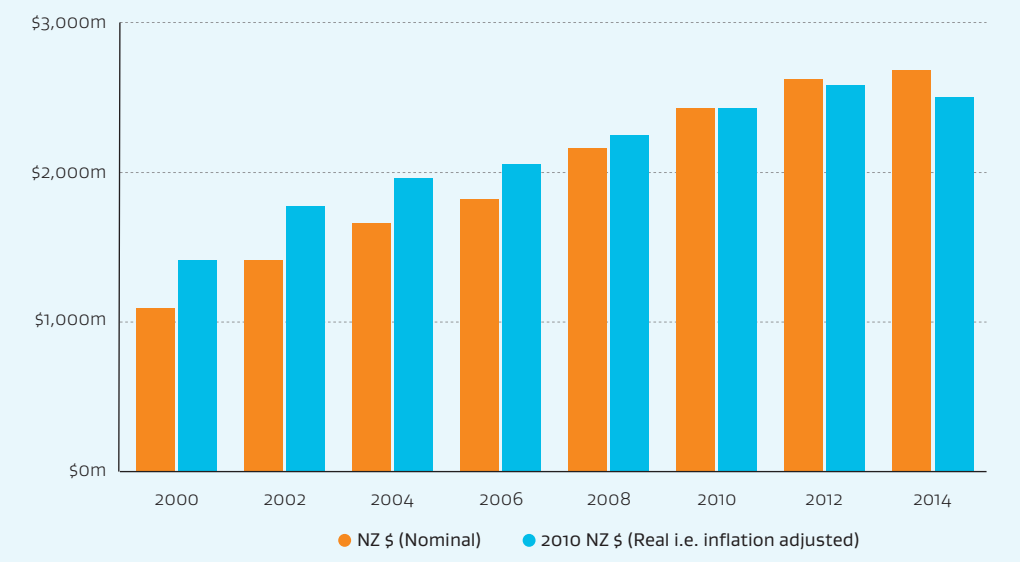


Figure 25 Total expenditure on R&D, nominal and real (inflation-adjusted)



Funding breakdown

This section shows how funding flows between the various key actors in the system. It shows the main science funding mechanisms, research providers, and trends in research spending. Data on the purpose of funded research indicate the areas of economy and society towards which research effort is focussed.

R&D EXPENDITURE BY FUNDER AND RECIPIENT

What it measures

This diagram shows the flow of funding from source (funder) to recipient (performer of R&D) in New Zealand's R&D system.

Figure 26 R&D funding by source and destination, 2014

Why it matters

This shows who is investing in R&D, where this investment is being made and where research capability lies. It indicates the value provided to the funder and also other connections between the funder and recipient (such as knowledge flows and collaboration).

What the data show

Government performs about one-quarter of R&D in New Zealand ($622m in 2014 – shown on the right-hand side of Figure 26). Figure 28 shows that government R&D has grown steadily in nominal terms since 2000. Real expenditure has also grown but less consistently.

New Zealand government R&D is relatively high among Small Advanced Economies, at 0.3 per cent GDP and on a par with that of Finland*. This is partly a result of the Crown Research Institute (CRI) model, in which approximately one-fifth of government R&D funding is directed to CRIs.

* 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.

Around one-third of New Zealand's total expenditure on R&D occurs in universities and other tertiary institutes. Tertiary sector research is integral to the education system. It allows teaching staff to stay at the forefront of knowledge in their field. By involving students in research it develops the skills and knowledge of the next generation of scientists and innovators.

New Zealand's higher education research expenditure has grown consistently in both nominal and real terms since 2000, with the exception of 2014 when it fell slightly in both nominal and real terms (Figure 27). 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 27 Higher education R&D, nominal and real (inflation-adjusted)

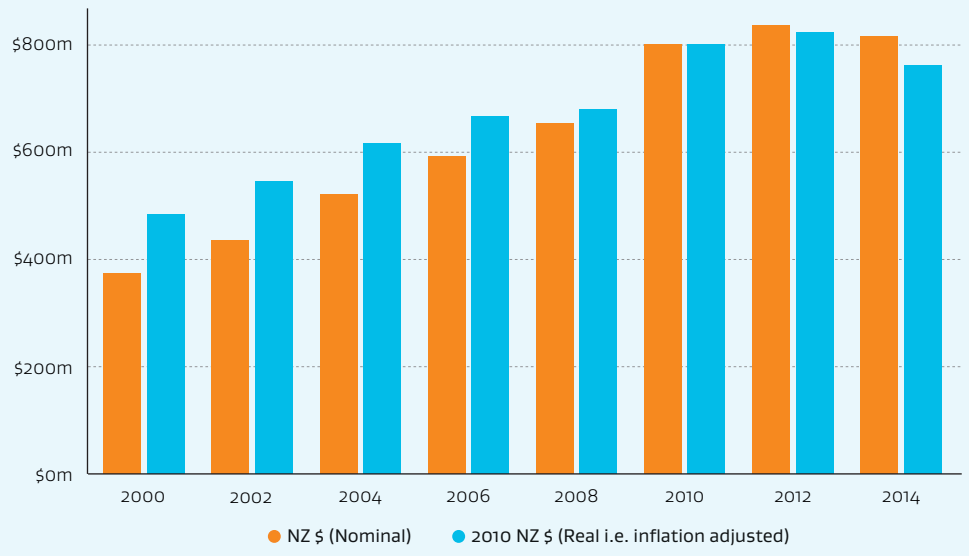


Figure 28 R&D performed by government, nominal and real (inflation-adjusted)

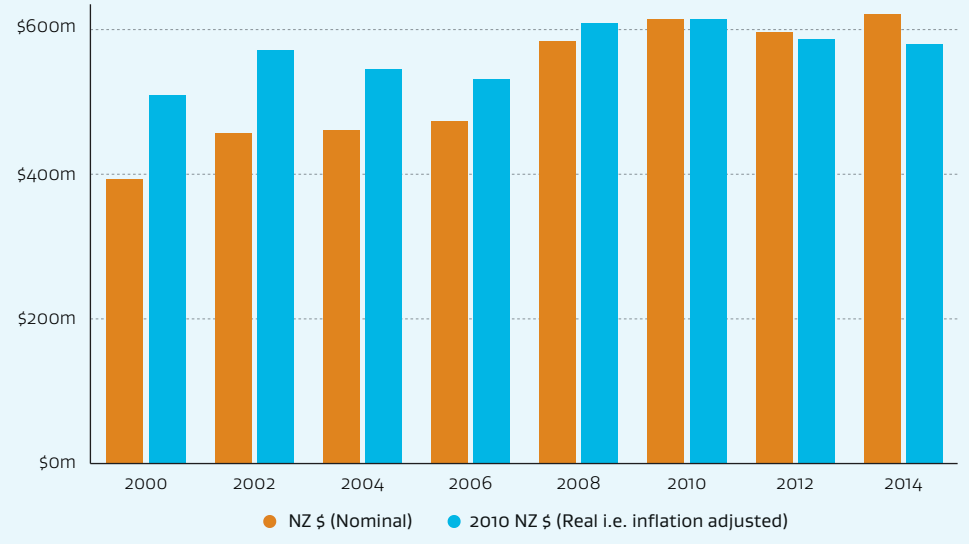
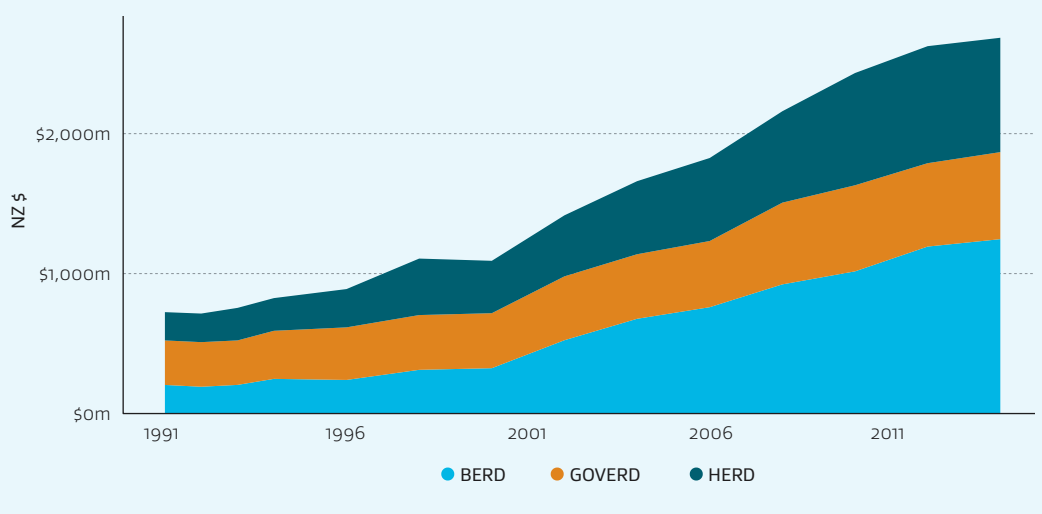


Figure 29 shows the (nominal) growth of R&D expenditure by sector over the last 25 years. It reveals that business expenditure has contributed the most to growth and has nearly doubled since 2000 to around 46 per cent of New Zealand's total R&D. Business expenditure on R&D is still relatively low when compared with other Small Advanced Economies and the OECD – the drivers of this are discussed further in the 'Focus on business R&D expenditure' section (p.22).

Figure 29 R&D growth by sector of performance, nominal NZ $



PUBLIC FUNDING OF R&D

What it measures

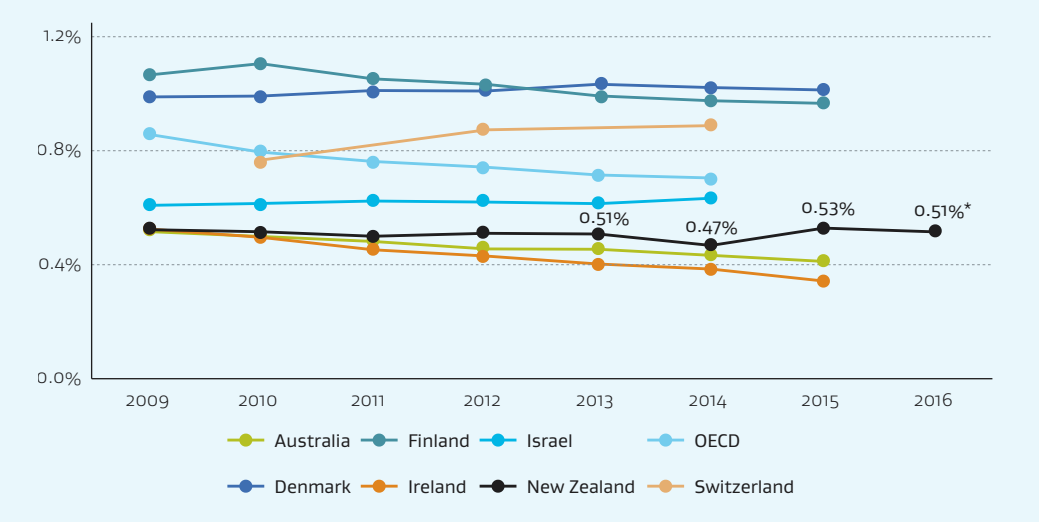
Public funding of R&D measures all government outlays on R&D, whether the expenditure itself occurs within government or in the private sector.

Why it matters

Governments fund R&D because it is likely to lead to broad benefits for the economy, environment and society. Individual firms are unlikely to be able to fully capture these benefits, leading to under-investment in R&D without government support.

What the data show

Figure 30 Public funding of R&D as a proportion of GDP

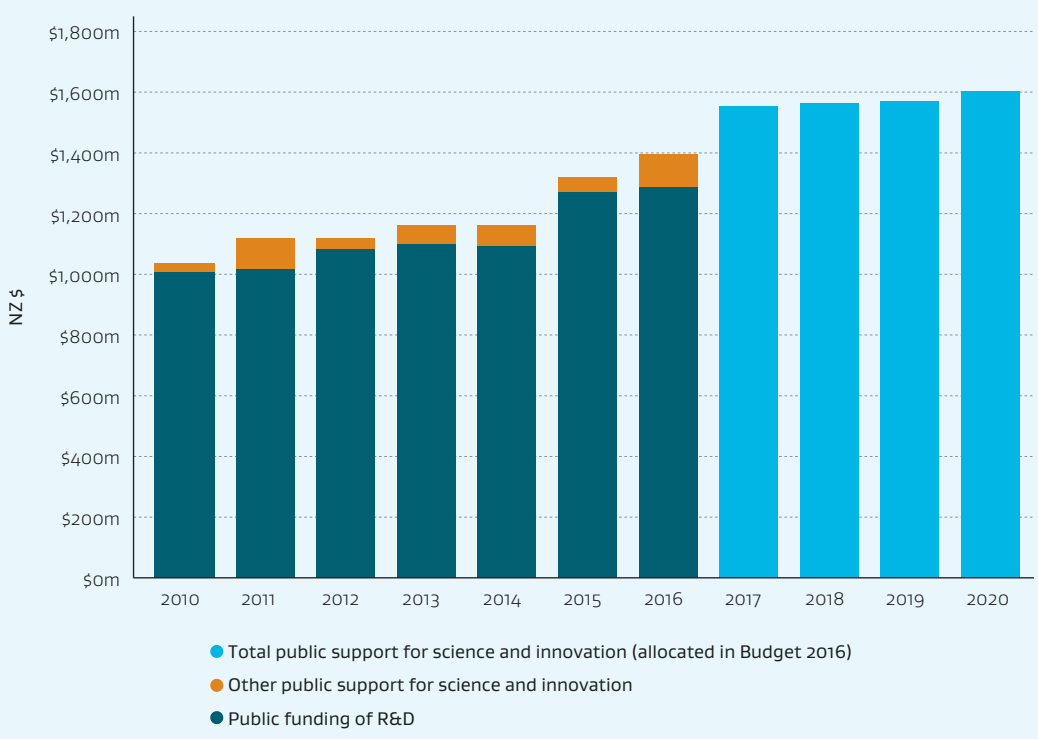


New Zealand's public funding of R&D is lower than the OECD average, is on a par with Ireland, Australia and Israel, but is significantly less than Denmark and Finland (which are among the highest in the world). Government's investment (in both real and nominal terms) has risen significantly over this period. The economy has also grown over this time, which has resulted in the percentage figure staying relatively constant.

* 2016 figure is estimated from reported expenditure in 15/16 Budget documents and partially forecasted 15/16 GDP

This measure includes a small amount of non-science research, and also excludes a significant amount of 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. As shown in figure 31, this expenditure is forecast to increase steadily to $1.6 billion by 2019/20, based on new funding allocated to science and innovation in the 'Innovative New Zealand' package as part of Budget 2016.

Figure 31 Total public support for science and innovation



PUBLIC FUNDING BY MECHANISM

What it measures

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

Some of the funds (such as the Primary Growth Partnership) include support for broader innovation and commercialisation activities. Smaller funding mechanisms are excluded so the totals do not reconcile to other measures of public science and innovation expenditure in this report.

Why it matters

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

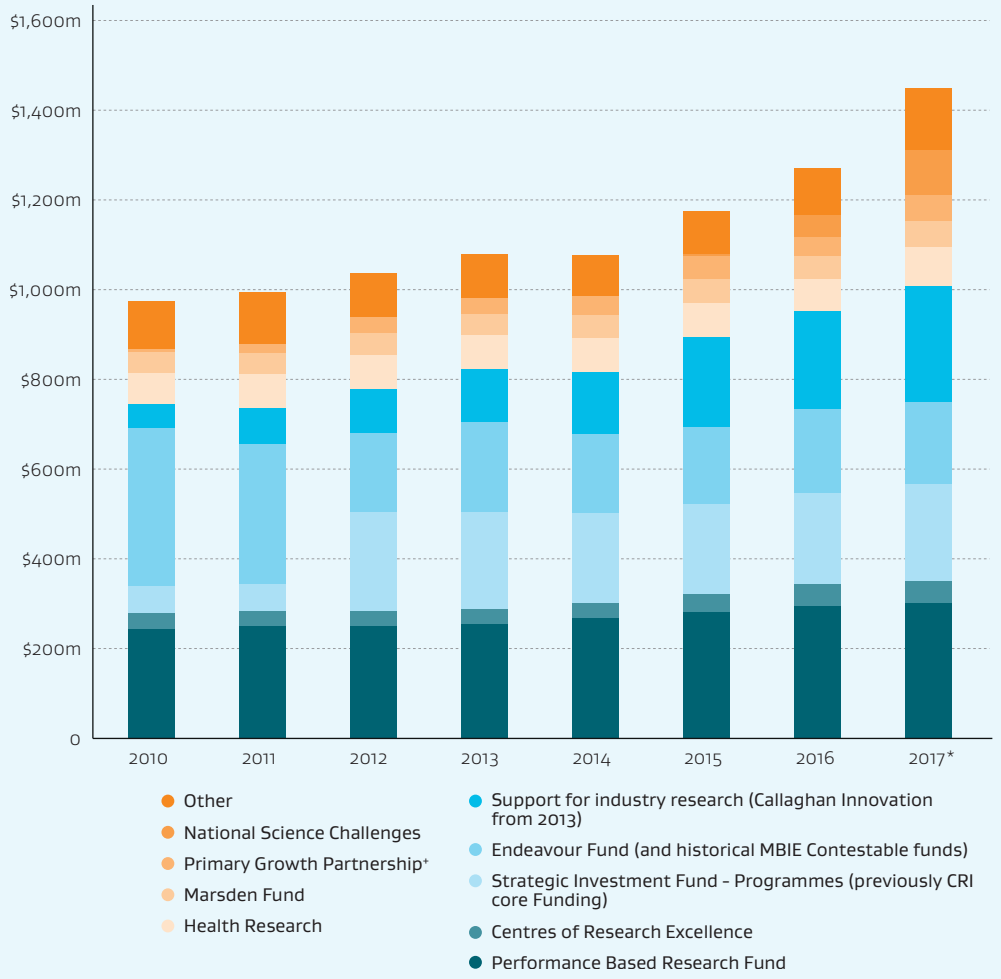
What the data show

Historically, the largest funding mechanisms have been the Performance-Based Research Fund*, Crown Research Institutes, 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.

Based on Budget 2016 figures, growth over the next four years is currently forecast to be driven by the Endeavour Fund, the Marsden Fund, health research, and the National Science Challenges. R&D Growth Grants are an 'on-demand' mechanism, so support for business R&D is likely to grow as demand from business increases as well as through investment in new Regional Research Institutes.

* Note that 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.

Figure 32 Public funding by mechanism – actual and forecast (2017 refers to financial year 16/17*)



* 16/17 figures are based on funding appropriated in Budget 2016. Potential inter-year transfers or underspends mean that actual expenditure in 16/17 may differ to that shown here.

\+ The Primary Growth Partnership figure is forecast 16/17 funding for committed PGP programmes as at 5 September 2016. This does not include any funding allocation for potential new PGP programmes.

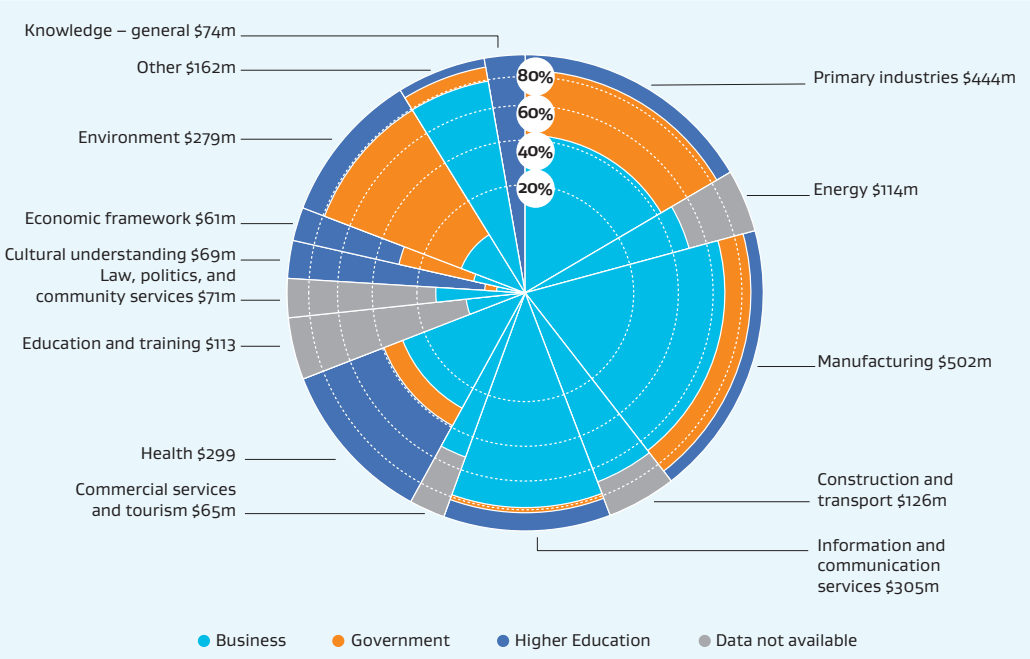
R&D EXPENDITURE BY PURPOSE OF RESEARCH AND SECTOR OF EXPENDITURE

What it measures

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 2014.

What the data show

Figure 33 Expenditure on R&D by purpose of research and sector of expenditure, 2014



The data reveals that government has a particular focus on performing environmental and primary industry research and contributes significantly to manufacturing R&D. Higher education is important in health (with an even spread over a large number of other areas), while business research is concentrated in ICT, manufacturing and primary industries.

The National Statement of Science Investment identified that government has a clear role as the primary investor in investigator-led research, and that increasing the funding for investigator-led research was a priority. The NSSI also stated that health and basic ICT research were a priority. The NSSI identified that future growth in primary sector R&D should be driven by industry, with government support.

Budget 2016 decisions supported these NSSI priorities with new public investment of $66m for New Zealand's premier investigator-led research fund, the Marsden fund. Budget 2016 also provided an additional $97m in funding for the Health Research Fund, which supports research of both investigator-led and mission-led orientation.

R&D EXPENDITURE BY RESEARCH HORIZON

What it measures

This measures the amount and proportion of funding that goes into basic research, applied research, and experimental development (close to market). The graph below adjusts for inflation and purchasing power parity across countries.

Why it matters

The National Statement of Science Investment notes that government's role as an investor is clearest in basic research, where the social returns are potentially high, and that too much of our science across government and industry is currently focused on low-risk projects with more certain short-term impacts.

What the data show

Applied research has increased in real terms since 2002 and now accounts for the highest proportion of New Zealand's R&D spend. Experimental development has also increased since 2002, but remains below applied research. Basic research spending has decreased since 2002, but has been fairly consistent since 2008. We spend a similar proportion on basic research to most other SAEs and Australia.

Figure 34 Expenditure on different types of research

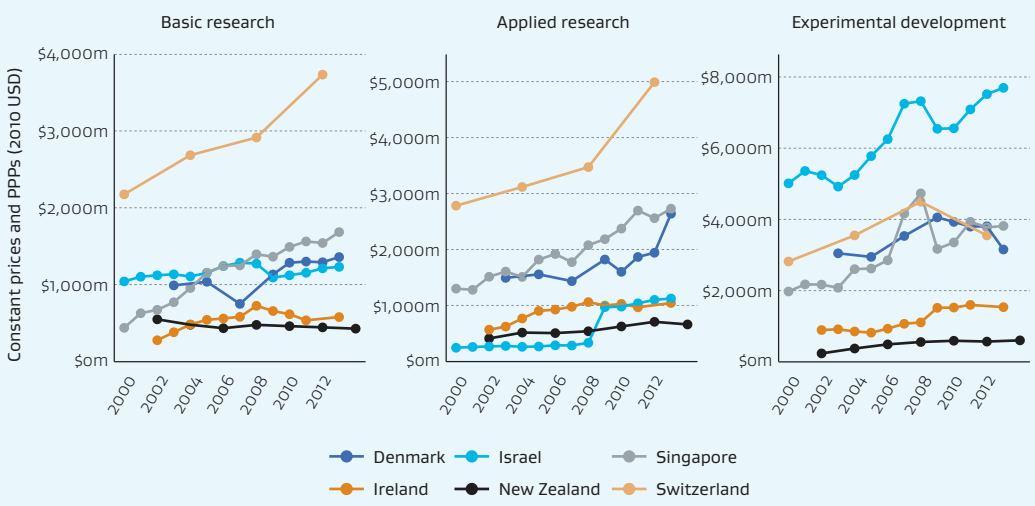
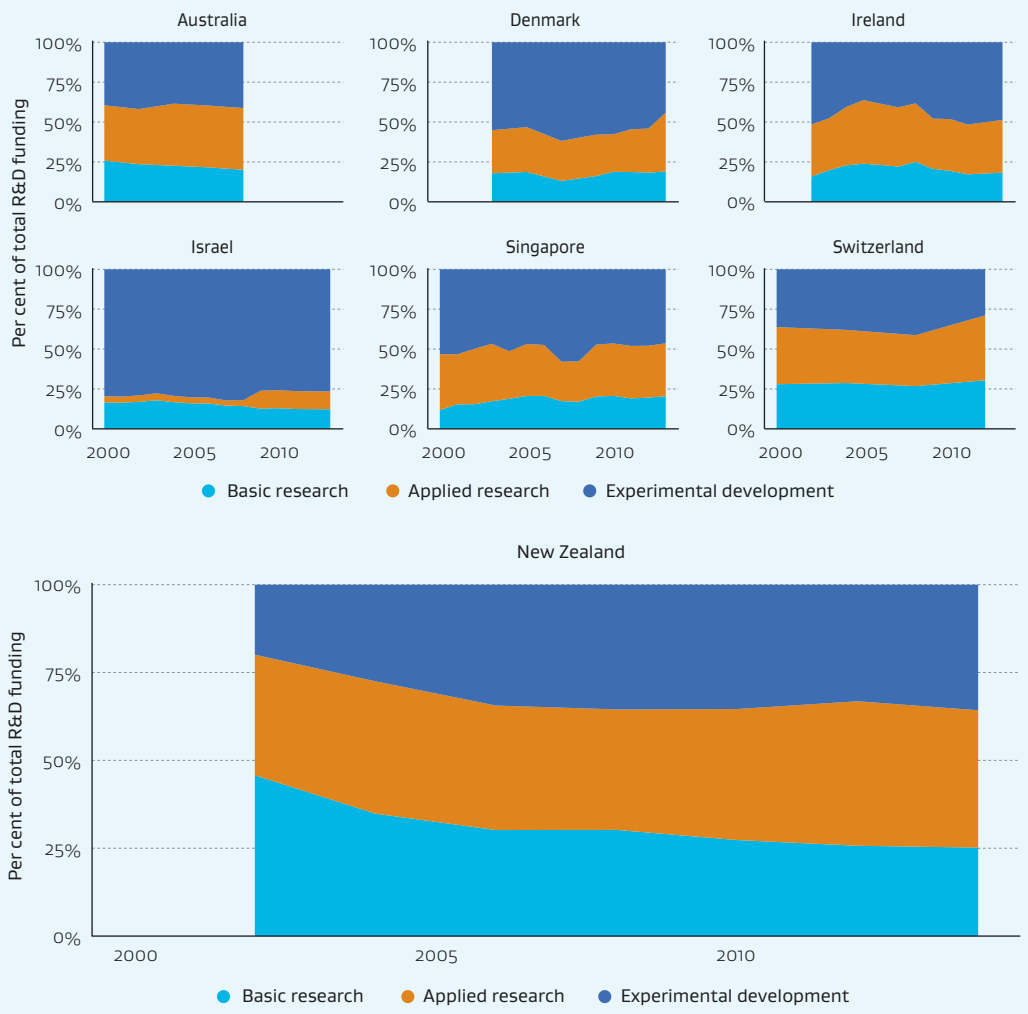


Figure 35 Proportion of research expenditure by type of research



* Note: These figures differ from those reported by Statistics New Zealand from the R&D survey, but match figures reported to the OECD and therefore allow fair international comparison. For example the total number of researchers reported by Statistics New Zealand in 2014 was 51,600 and the OECD number (reported as 2013 in the OECD stats) was 43,200. The OECD figures for New Zealand do not include Masters students.

People

Researchers are at the core of the science and innovation system. They supply the skills, knowledge, creativity, connections and human resource to apply, create and communicate knowledge using the scientific process. This section presents basic data on who New Zealand's researchers are and where they work. Section 3 on the 'skills pipeline' 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.

NUMBER OF RESEARCHERS

What it measures

This includes all people employed in R&D activities, including researchers, students, technicians and other support staff working in this area.

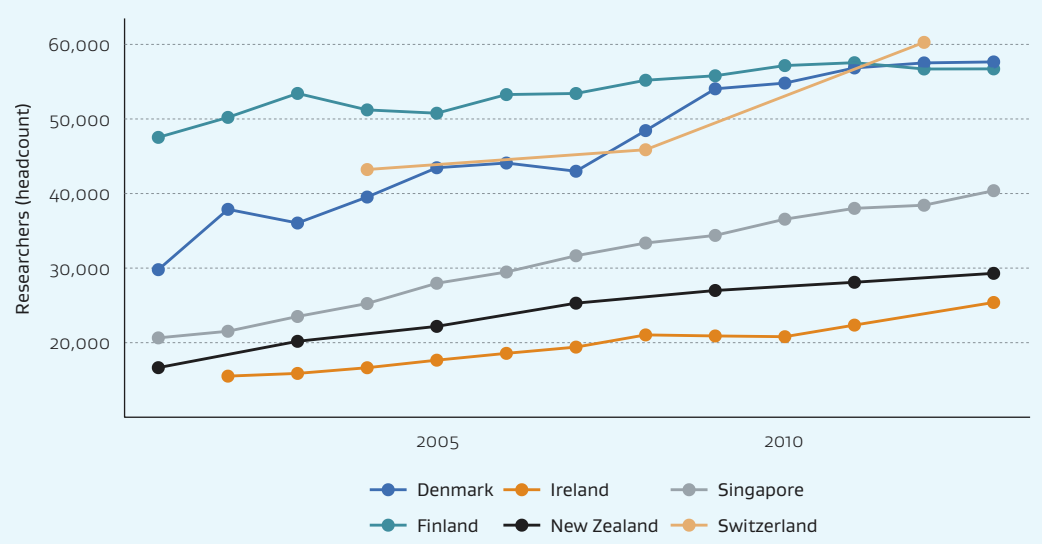
Why it matters

This is an alternate indicator (to funding) of the size of the R&D system.

What the data show

The number of researchers in New Zealand has increased by 76 per cent from 2001 to 2013.

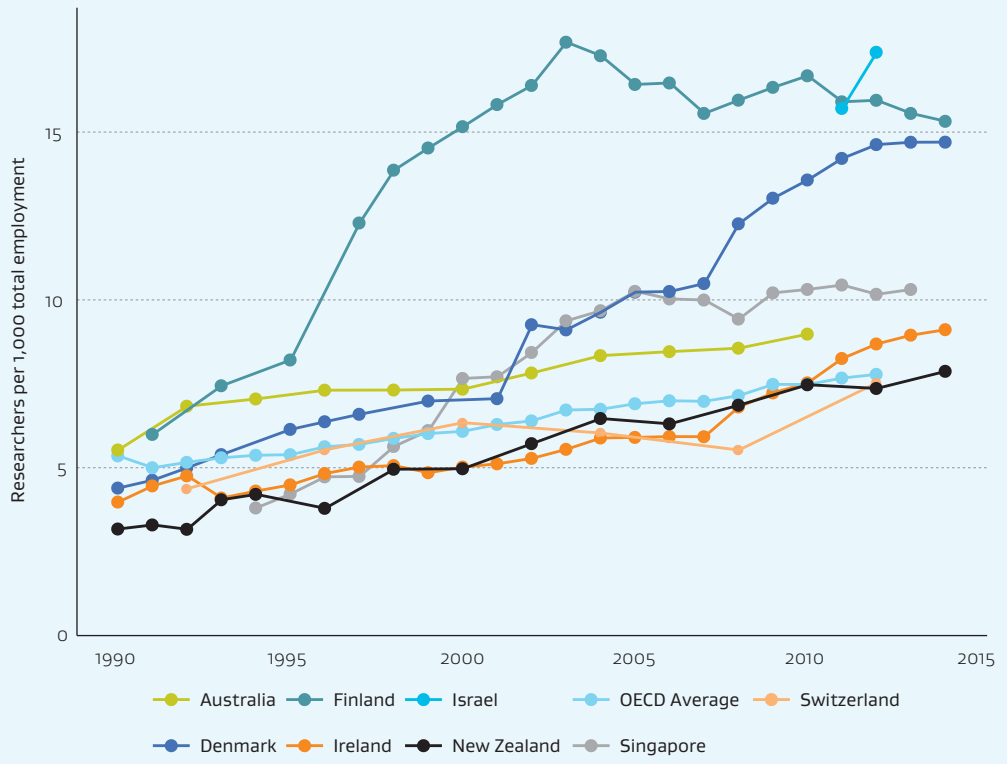
Figure 36 Number of researchers*



Researchers per 1000 employment indicates what proportion of the working population is engaged in R&D. New Zealand's relatively low score compared with other Small Advanced Economies is consistent with the relatively small size of our science and innovation system.

New Zealand has a similar proportion of researchers in the workforce to the OECD average. Given we spend a smaller fraction of GDP than the OECD average on R&D, this suggests costs per researcher are relatively low in New Zealand. This does not necessarily reflect lower salaries, since research costs also include institutional overheads and research infrastructure. New Zealand research is likely to be less capital intensive than research in the large OECD countries, and this probably plays a role in increasing our total R&D costs per researcher.

Figure 37 Researchers per 1000 employment



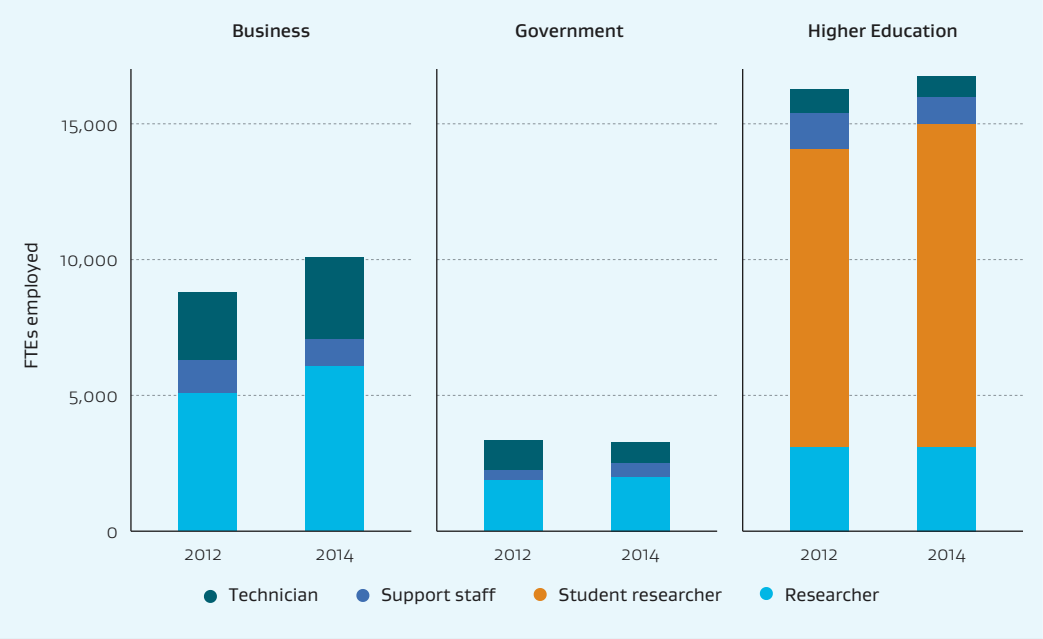
SPLIT OF RESEARCHERS BY SECTOR (GOVERNMENT, HIGHER EDUCATION, BUSINESS)

What it measures
This shows where researchers work.

Why it matters
This indicates the amount of research conducted in the different sectors.

What the data show
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. From 2012 to 2014, the number of researchers in business and the number of student researchers in higher education have increased significantly. This is indicative of increasing business R&D, and an increase in the size of the skills pipeline towards research.

Figure 38 Researchers by sector (Full-time-equivalents)



RESEARCHER DEMOGRAPHICS

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

GENDER SPLIT OF RESEARCHERS

What it measures

These measures the gender split of researchers in each field and how that has changed between 2006 and 2012.

Why it matters

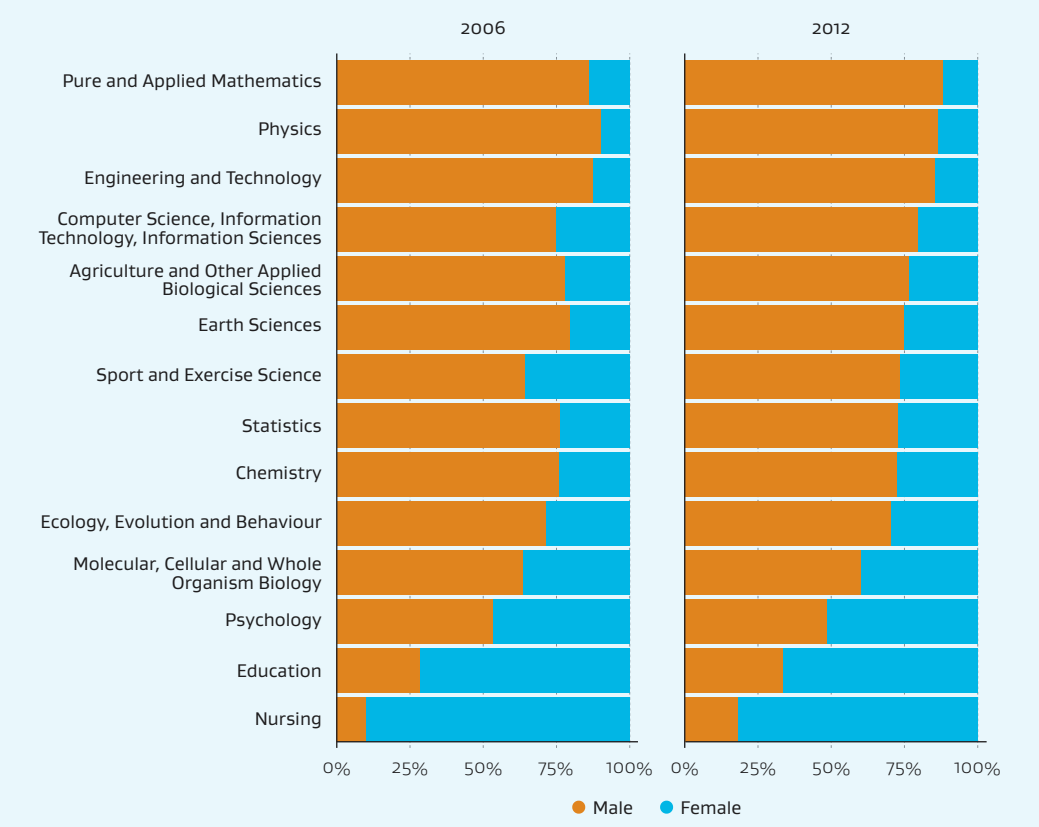
The gender split of researchers is an indicator of equal opportunities to participate in society and how well diverse perspectives are incorporated in R&D. It may reflect where research fields have higher barriers to entry for one gender, as well as the gender split in students studying those fields (i.e. the skills pipeline).

What the data show

Male-dominated fields appear at the top of the chart and female-dominated fields at the bottom.

Some male-dominated fields have become slightly more gender balanced between 2006 and 2012 (physics and earth sciences) whilst others now have an even smaller proportion of women (IT and mathematics). Nursing has shown a shift in the other direction – moving from 10 per cent to 18 per cent men between 2006 and 2012.

Figure 39 Proportion of male and female researchers by field, 2006 and 2012



ETHNIC BACKGROUNDS 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 2011), Europeans are over-represented among researchers (81 per cent of researchers vs 69 per cent of general population). Asians are under-represented (4.4 per cent vs 12 per cent), as are Māori (1.7 per cent vs 13 per cent) and Pacific Peoples (0.6 per cent vs 6 per cent).

Doctoral degree completion data for domestic students (2014) suggests that this imbalance may decrease in the next generation of researchers. Of those completing research degrees during this period, 7.1 per cent identified as Māori and 1.9 per cent identified as Pasifika. A further 16 per cent identified as Asian. The impact this has on the composition of the future research workforce depends on whether these graduates go on to be researchers in New Zealand.

Infrastructure

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

- 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
- New Zealand Genomics Limited
- the Australian Synchrotron – generates 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.

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.

Taxonomic collections

New Zealand's taxonomic collections and databases (some of which receive Nationally-Significant Databases and Collections funding) underpin scientific knowledge about our unique living systems. They support primary industry export certification, biosecurity responses, environmental impact assessment, international and domestic biodiversity reporting obligations, human pathogen identification, and research in biological science and ecology.

A 2015 report by the Royal Society found that New Zealand's taxonomic knowledge is relatively undeveloped compared with other advanced economies. It found financial support is declining and is inadequate to develop or maintain the existing assets and expertise, while demand for their services is increasing. It recommended appropriate legal protection for the collections, and a national oversight, coordination or investment strategy.

Strategic Science Investment Fund

As part of Budget 2016, the Government announced the Strategic Science Investment Fund (SSIF), which includes public science infrastructure funding. Future infrastructure investment decisions will be informed by a long-term investment plan and roadmap for infrastructure as well as a consistent approach to performance assessment. Assets considered will include those currently receiving direct government funding and others with less secure funding (such as some of the taxonomic collections, the New Zealand Land Cover Databases and the S-Map soils database (see case study on page 36). This approach will allow investment decisions to be made on a consistent and strategic basis, to ensure the infrastructure supported provides key services and supports excellent science in New Zealand. Indicators will be developed for future reports that reflect the direction set in the investment plan and infrastructure roadmap.

Section 3:

Supporting factors

Skills pipeline

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 schooling and tertiary education system or brought in by migrants to New Zealand.

TIMSS SCORES FOR YEARS 5 AND 9 (TRENDS IN INTERNATIONAL MATHEMATICS AND SCIENCE STUDY)

What it measures

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) and is more curriculum and schooling aligned than some studies such as the Programme for International Student Assessment (PISA). This means that it provides information during schooling, rather than an assessment of cumulative learning at the end of compulsory schooling.

The Scale is set so that 500 in 1995, the first year, was the international average, and 100 points either side corresponds to one standard deviation.

Why it matters

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 innovation. Recent OECD evidence indicates that skills in mathematics directly correlate with increased incomes.

What the data show

At year five, our primary school children score below the international average (500 points) for Mathematics and around the average for Science. We score relatively low compared with other Small Advanced Economies and Australia. At year nine, the pattern is similar, although New Zealand appears slightly closer to the scores of other Small Advanced Economies.

Figure 40 Year five scores on Trends in International Mathematics and Science Study

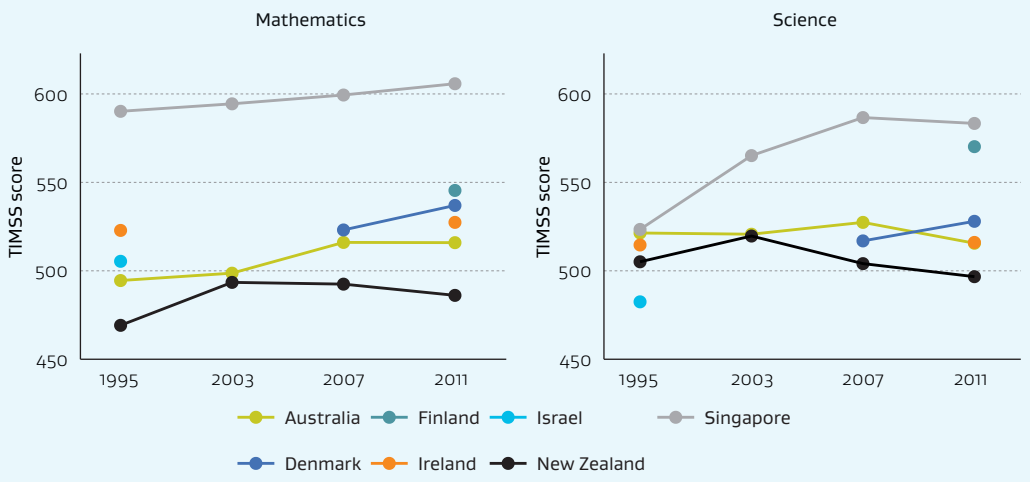
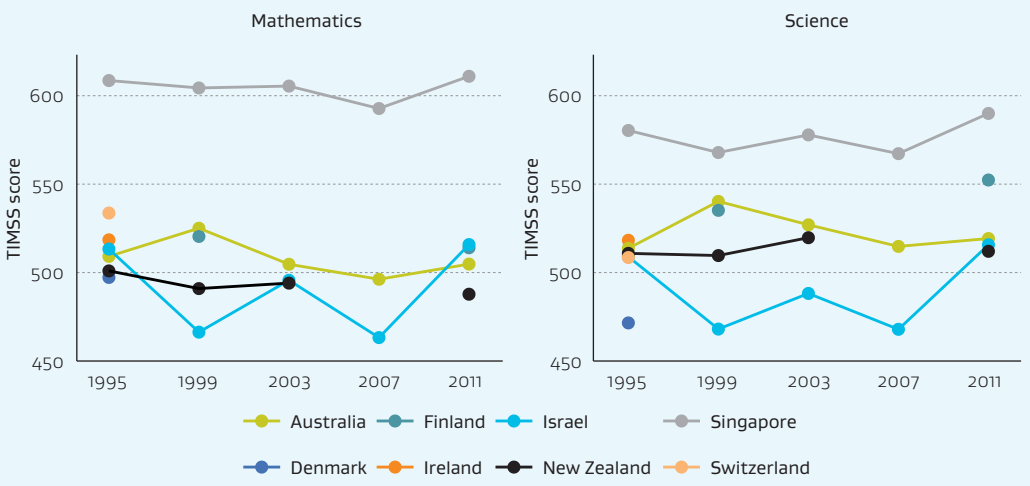


Figure 41 Year nine scores on Trends in International Mathematics and Science Study



SCHOOL LEAVERS' ATTAINMENT IN MATHEMATICS AND SCIENCE

What it measures

This shows the proportion of school leavers who attained at least 14 credits in a learning area at Level 1, Level 2 or Level 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.

Why it matters

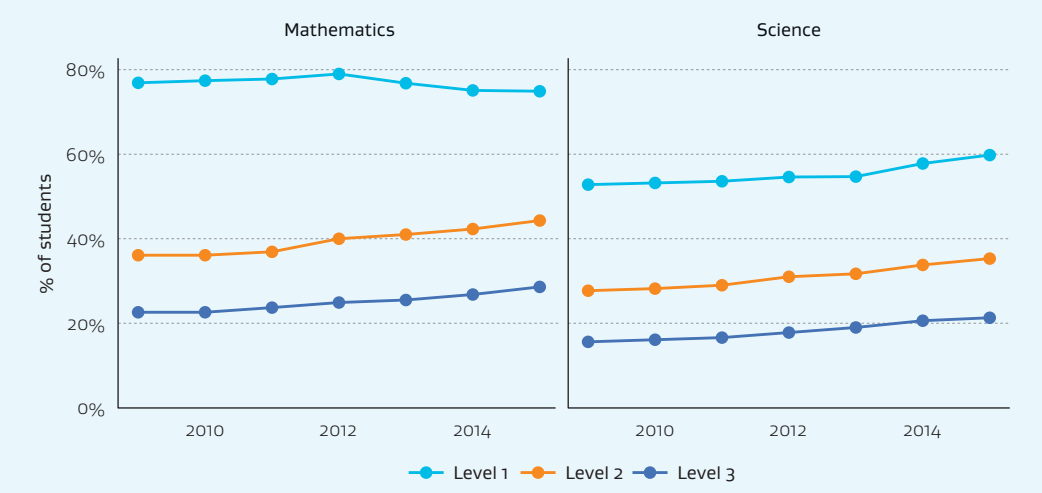
Achievement in Mathematics and Science at this level contribute to Science, Technology, Engineering and Mathematics (STEM) skills for all students – for those that do go on to STEM subjects at NCEA Level 3 and tertiary and those who are on other learning pathways.

What the data show

For Mathematics and Statistics the proportion of school leavers attaining Level 2 and Level 3 increased steadily since 2009. However, the proportion of school leavers attaining Level 1 has decreased since 2012. 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 all levels since 2009.

Figure 42 Proportion of School Leavers Achieving at least 14 credits in Mathematics and Sciences at Levels 1–3



GRADUATES IN STEM SUBJECTS PER ANNUM

What it measures

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

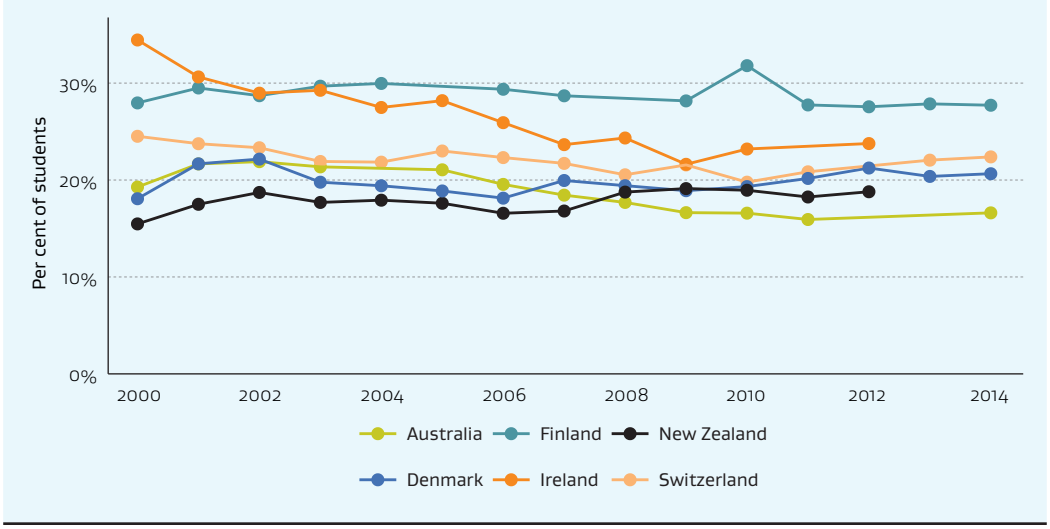
Why it matters

To successfully innovate, businesses need access to a broad range of highly skilled labour. In addition to critical thinking, broader academic and technical training, innovation is supported by strong foundational and advanced STEM skills. There is also evidence that international students, with the perspectives, diversity and international connections that they bring help to increase innovation.

What the data show

Tertiary students graduating in STEM subjects have increased as a percentage of total New Zealand graduates since 2000. New Zealand overtook Australia in 2008 but remains low compared to other Small Advanced Economies on this measure.

Figure 43 Proportion of New Zealand graduates who are in STEM subjects



Within STEM subjects, the Science and Mathematics component of is one of the highest in the OECD (63 per cent of STEM vs 39 per cent OECD average), while Engineering is relatively low. In 2012, the Government introduced the Engineering Education to Employment programme, with the aim of increasing the number of engineering graduates, in response to an anticipated shortage. Budget 2015 invested an additional $86 million over four years for targeted increases in funding for STEM subjects at degree level and above. The impacts of these policies will not yet have had had time to appear in these results.

At the absolute level, fewer domestic students are attaining STEM certificates and diplomas, but this has been largely 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 44 People completing qualifications in STEM fields
(Natural and Physical Sciences, Technology, Engineering and Maths)

INWARD MIGRATION OF SCIENTISTS AND STEM PROFESSIONALS

What it measures

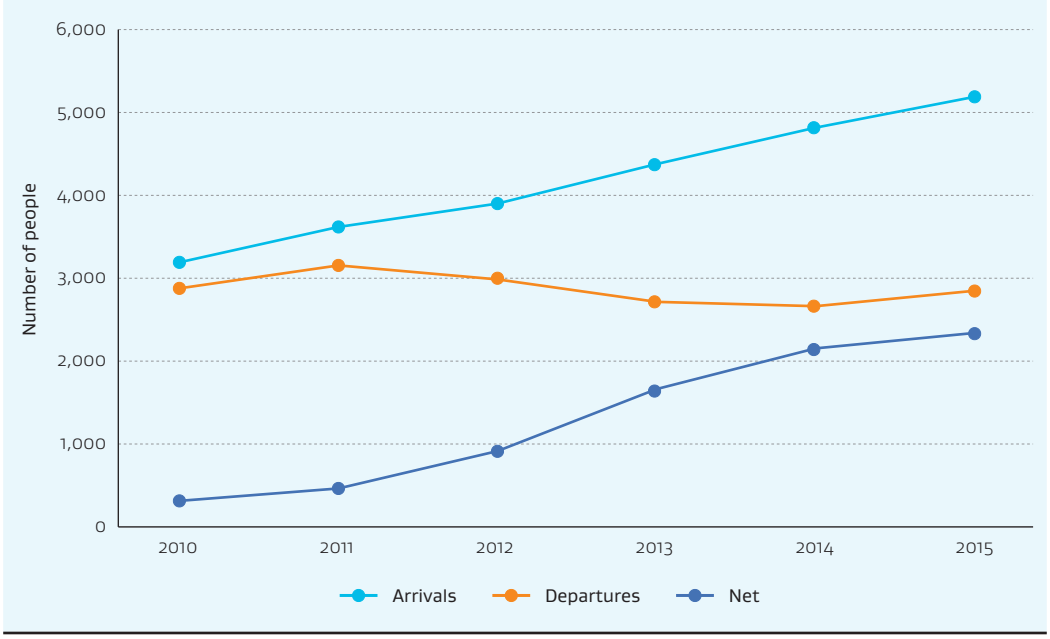
This indicator shows the number of permanent and long-term arrivals/departures (for more than 12 months) of people in a science, engineering or IT-related occupation.

Why it matters

This shows whether New Zealand has a net 'brain gain' or 'brain drain'. Migrants are an important source of skills for New Zealand's science and innovation system. The loss of significant numbers of talented New Zealand STEM professionals overseas would also be a cause for concern. Successfully attracting or retaining people with these skills indicates an internationally-competitive science and innovation system.

What the data show

Figure 45 Inward migration of STEM professionals

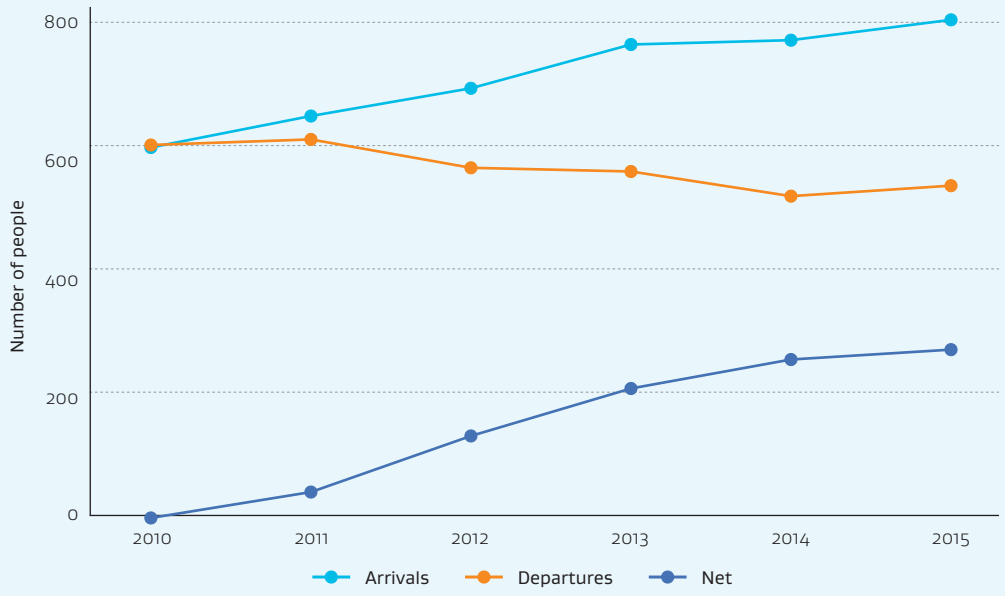


The data show that New Zealand has had a net, and growing, 'brain-gain' of both scientists and STEM professionals* overall since 2010. A steady number depart each year, but a greater number arrive, and this is steadily growing year-on-year.

About 50 per cent of STEM arrivals are engineers, with about one–third in IT-related occupations and 12 per cent in 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 46 Inward migration of science professionals



Early career researchers

BACKGROUND

Early career researchers are an important part of the science system.

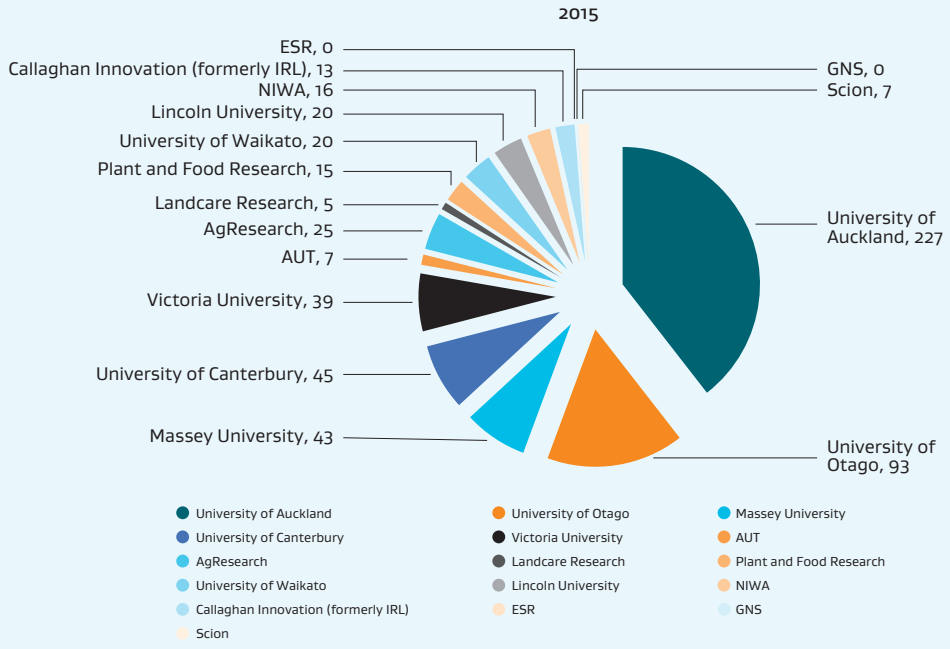
In line with the international definition, we define post-doctoral researchers as individuals who have six or fewer years' experience of active research after receiving a doctoral degree. They are engaged in a temporary and defined period of research or mentored advanced training, to enhance the professional skills and research independence needed to pursue their chosen career path.

NEW ZEALAND'S POST-DOCTORAL RESEARCHERS

MBIE performed a survey in 2012 which asked New Zealand universities, Crown Research Institutes and Callaghan Innovation how many post-doctoral positions were in their organisation. This found a total of 592 positions throughout New Zealand. The survey was repeated in 2015, and found the number of post-doctoral positions had decreased by 3 per cent to 575. The 2015 results are displayed below.

International comparison data on post-docs are not complete and not prepared on a consistent basis. New Zealand appears to have a similar proportion of post-doc researchers as the United States (around 3 per cent) but a smaller proportion than Denmark (9 per cent), although these comparisons are not necessarily robust.

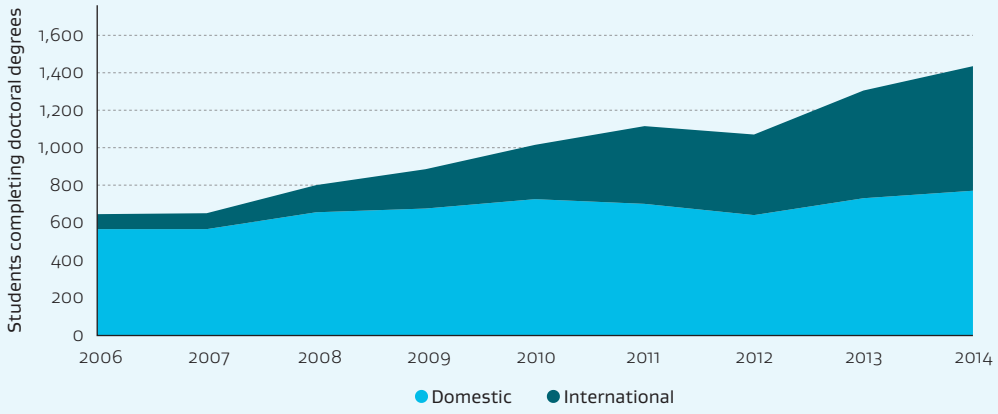
Figure 47 Post-doctoral researchers by institution in 2015



New Zealand is producing more PhD graduates each year. This has primarily been driven by an increasing share of international PhD students, which increased from 18 per cent of PhD graduates in 2008, to 46 per cent in 2014. This followed a policy change in 2005 which meant that international PhD students pay domestic fee rates. In total, New Zealand produced 1,435 doctoral graduates in 2014, up from 1,065 in 2012.

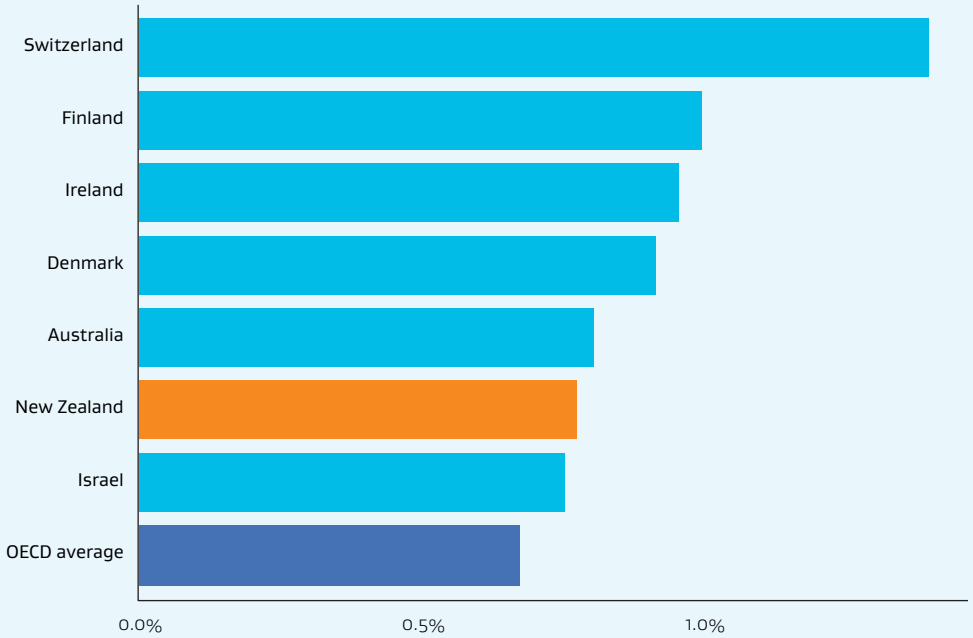
* Denmark estimated to have 3,598 post-docs (http://dg.dk/filer/Publikationer/The-Post-doc-Challenge.pdf). United States estimated to have at least 40,000 post-docs (http://www.nature.com/news/the-future-of-the-postdoc-1.17253#/postdoc). Proportions derived by dividing by total researcher FTEs from OECD data.

Figure 48 PhD graduates produced per year in New Zealand



Compared internationally, New Zealand produces PhD graduates overall at a higher rate than the OECD average, at a similar rate to Israel and Australia, but at a lower rate than the remaining Small Advanced Economies. Given New Zealand's relatively low R&D expenditure compared with these countries, this suggests it is producing PhDs at a high rate for the size of its research system.

Figure 49 Doctoral graduation rate: Science and Engineering PhDs awarded as a proportion of the country population at the typical graduation age



INTERNATIONAL MOBILITY

New Zealand's PhD graduates are highly mobile internationally, with approximately 30 per cent of young domestic doctorate graduates going overseas in their first year post study, although it appears that some return after completing post-doctoral placements overseas.

More broadly a 2014 report found that overall New Zealand's loss of local researchers and gain of foreign researchers balances out. It found that New Zealand is exporting quality researchers to the United Kingdom and the United States (as measured by researchers' field-weighted citation impact (FWCI) scores). However, researchers returning to New Zealand tend to be more senior with higher FWCI scores than leavers. New Zealand is also successfully attracting overseas talent with higher FWCI scores than the New Zealand average.

Public engagement with science

A NATION OF CURIOUS MINDS / HE WHENUA HIHIRI I TE MAHARA

A Nation of Curious Minds / He Whenua Hihiri I Te Mahara is the Government's strategy to encourage and enable better public engagement with science and technology.

It aims to support the science sector's 'social licence', meaning an environment of mutual understanding and transparent communication between the public and the science sector. This is important so that New Zealanders are fully equipped to participate in the tough decisions about public health, natural resources stewardship or new and emerging technologies.

It also aims to create a workforce who are increasingly-competent in STEM disciplines. Such skills are thought to be important (among others) in solving problems and creating and delivering high-value products and services, and ultimately a more 'innovation-focused' society.

RESULTS OF THE NIELSEN SURVEY ON PUBLIC ATTITUDES TOWARDS SCIENCE AND TECHNOLOGY

Public engagement with science index

This is a composite index of scores on aspects of attitudes and behaviours related to science as assessed in the 2014 Nielsen survey of 3004 New Zealanders.

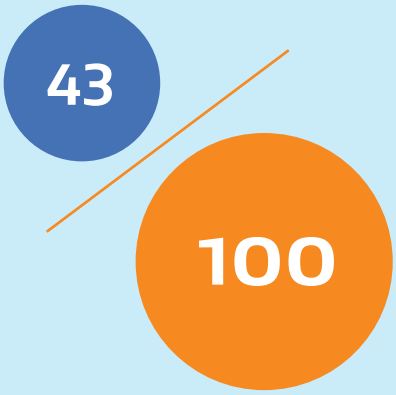
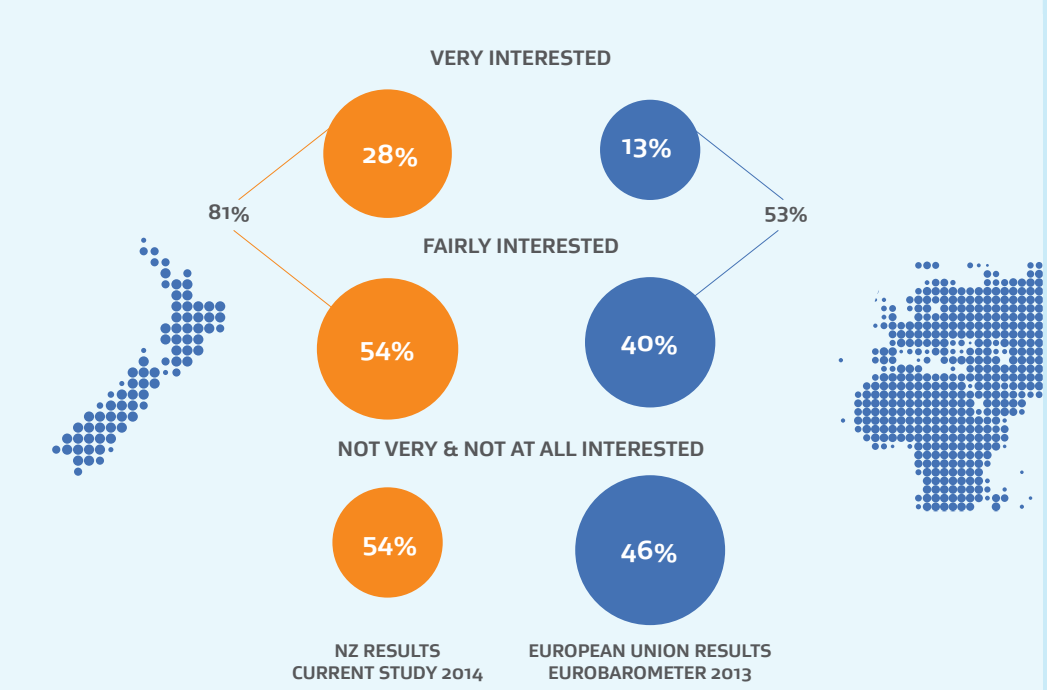


Figure 50 compares results on the level of public interest in science from the New Zealand survey with similar data from the European Union.

Figure 50 The level of public interest in science in New Zealand and Europe



More New Zealanders express an interest in science than in European countries (81 per cent compared to 77 per cent for Sweden – the best-scoring European country). New Zealanders also feel better informed about science than Europeans do (we rank second behind Denmark on this measure).

Key findings

New Zealanders are generally interested in science and technology and see it as important for themselves, for society, the environment and the economy. Engagement has improved over the last five years.

- 90 per cent agree it is important to study science at school and 83 per cent thought it worthwhile as a career.
- Compared with 2010, more people identify themselves as enjoying following science and less people have a lack of trust and interest in it. This engagement with science and technology appears to be strong via the media.
- A good willingness to directly support science was present, with 44 per cent saying they had donated money to support scientific research.

There are some areas where engagement and relevance of science for New Zealanders could be improved:

- Accessibility of scientific information is an issue: 42 per cent of people say they get too little information about science; 35 per cent think science and technology are too specialised to understand; and 51 per cent think there is too much conflicting information about science and technology "making it hard to know what to believe".
- A majority (62 per cent) think that scientists need to listen more to what ordinary people think, suggesting more work is needed on scientific engagement with the community.
- Young females are less interested in technology as an important topic to study at school and also feel significantly less well informed about science than males.
- Only 39 per cent agree that Mātauranga Māori (traditional Māori knowledge) has a role in science, suggesting a challenge to communicate and embed the Vision Mātauranga policy.

Connections

The free flow of knowledge and ideas is fundamental to the 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 and enriches scientific and technological progress by exposing people to unfamiliar concepts, and increases the chances that ideas and findings are picked up and have an impact in society and the economy. Connecting with science and innovation in the rest of the world keeps New Zealand abreast of the global knowledge and technology frontier.

PROPORTION OF PUBLICATIONS WITH ONLY ONE AUTHOR

What it measures

This indicator shows what proportion of publications have only one author. It is the inverse of the rate of co-authored papers. This is used to show the extent to which researchers are collaborating.

Why it matters

A number of studies have consistently shown that collaboration between researchers is associated with greater citation impact [4,5]. 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. Greater author numbers per paper have been consistently associated with greater citation impact over this period. However, returns from collaboration have diminished over time – larger teams are now necessary to achieve a given citation impact.

We are interested in collaboration because it is likely to result in greater mixing and cross-fertilisation of ideas across research domains. The dramatic growth in the breadth and depth of scientific knowledge over the last century has also diminished the capacity of any single researcher to comprehend enough existing knowledge to make scientific progress in isolation. It is likely that the most complex scientific problems can only be effectively tackled by researchers with complementary expertise.

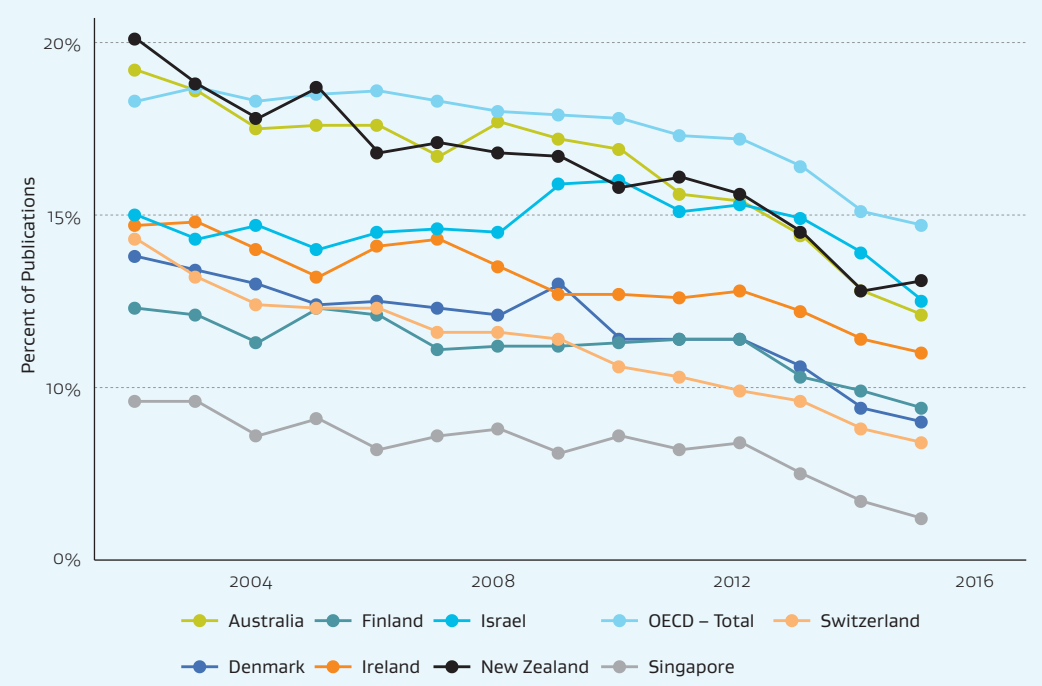
Possible criticisms of this indicator are that co-authorship improves citation impact because the work gains more 'self-citations' from the authors themselves. Also it may be that higher-quality researchers are more likely to collaborate, rather than collaboration increasing research quality. However, the evidence shows that collaboration leads to greater research quality, even after accounting for self-citations.

What the data show

New Zealand does marginally better than the OECD average on this indicator – our proportion of single-author papers is lower. We have a similar rate of single-author papers to Australia and Israel but we do not do as well as the other Small Advanced Economies. The rate of single-authorship is continuing to fall in New Zealand and across the OECD, indicating that more collaboration is taking place between researchers.

This indicator does not show the size of the collaborating teams or whether they are single- or multi-discipline. Nor does it take account of the propensity to collaborate in different fields. This will be covered in future system performance reports. There are likely to be greater 'transaction costs' associated with coordinating larger research teams which could diminish the returns from increasingly large teams. It will be interesting to analyse and track how New Zealand's scientific performance is affected by these dynamics over time as collaboration continues to grow.

Figure 51 Proportion of publications with only one author



PROPORTION OF PUBLICATIONS WITH INTERNATIONAL COLLABORATION

What it measures

This indicator shows the proportion of research output with authors from more than one country.

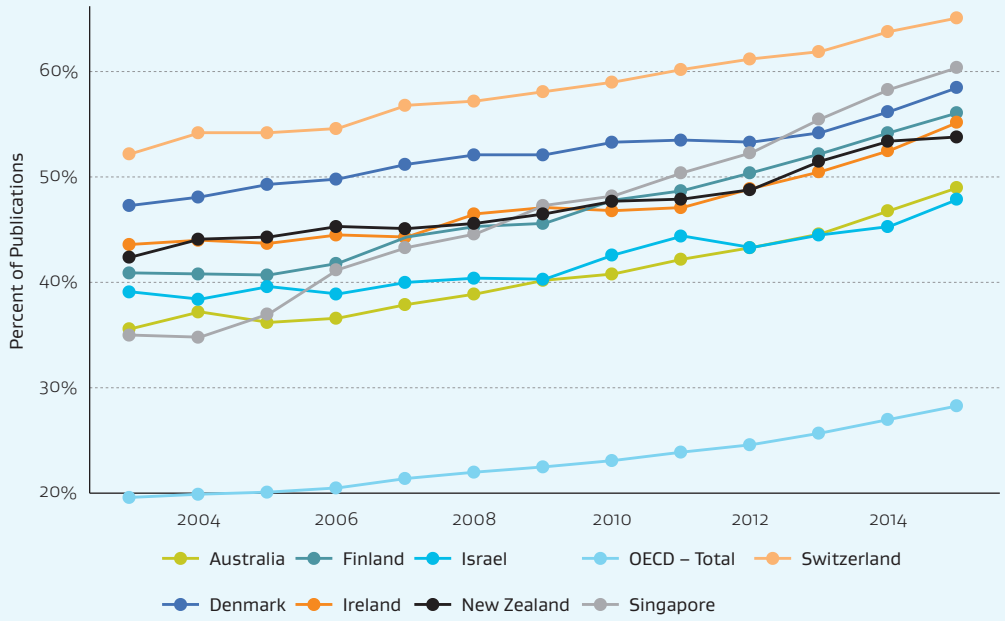
Why it matters

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[5,6].

What the data show

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

Figure 52 Proportion of publications with international co-authorship



International collaboration is likely to increase the cost of research, especially for New Zealand, given its relative geographical isolation. Research has shown that the correlation between citation impact and international collaboration varies with the countries collaborating and the field[6]. This suggests it is important to choose international collaboration partners carefully.

Figure 53 New Zealand's international collaborations by country, 2010–14

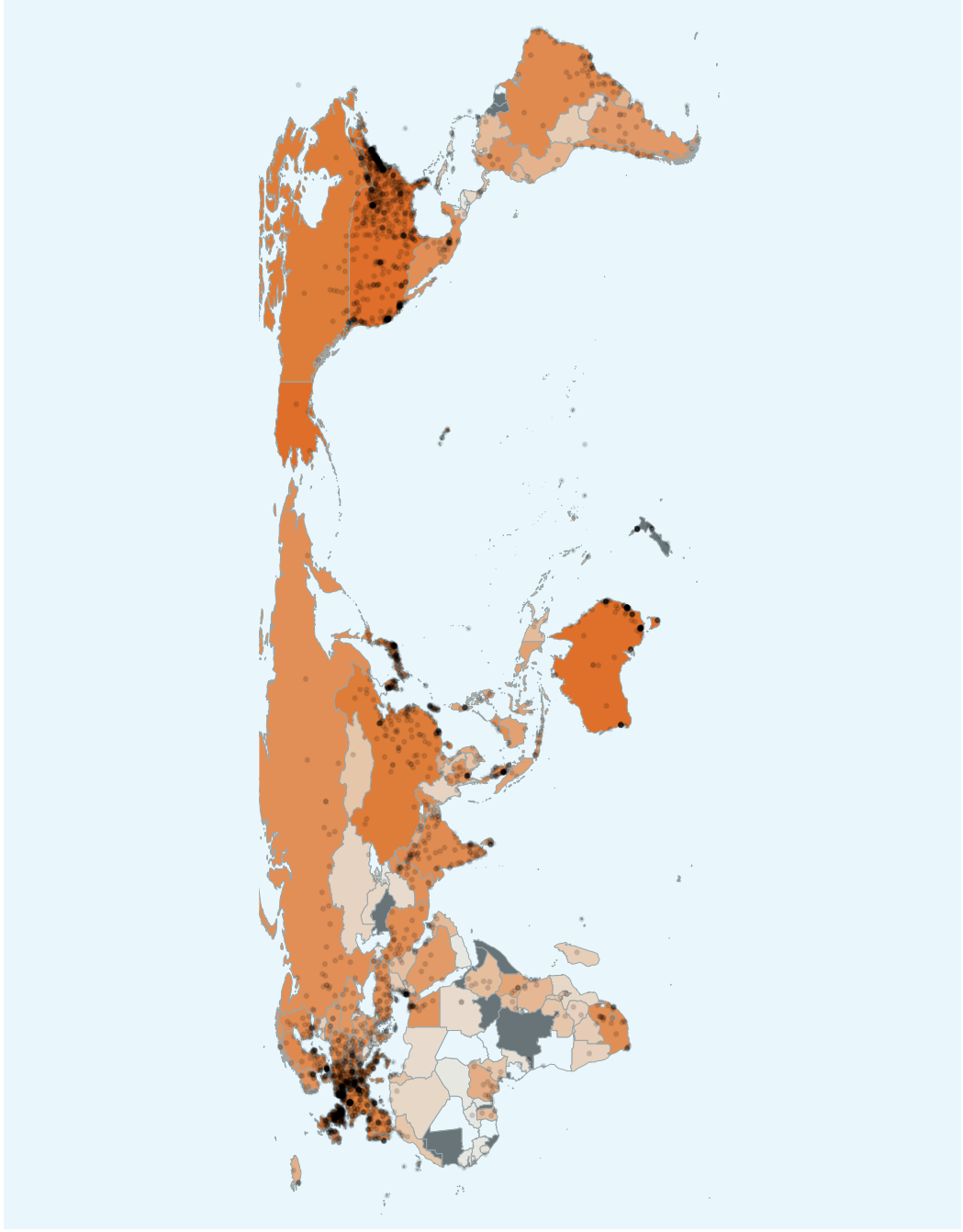


Figure 53 shows New Zealand's international collaborations on papers authored between 2010 and 2014. This illustrates the extent of our researchers' links with institutions in the US, Europe and Australia.

The government provides funding for global science partnerships for New Zealand through the Catalyst Fund ($12.7m in 2016/17). This supports researchers to participate in large and small scale international collaborations, to enhance knowledge creation in New Zealand and gain access to research infrastructure and resources in strategic areas. The fund also supports participation in key international science fora to help influence the direction of global research agendas.

- Our top collaborator countries, in order, are the US, Australia, UK, Germany, Canada and China. Nearly half of our international co-authored papers include these countries.
- Our top fields for international collaboration, in order are:
  - Medicine
  - Agricultural and Biological Sciences
  - Biochemistry, Genetics and Molecular Biology
  - Engineering
  - Earth and Planetary Sciences

Around half of our international co-authored papers are in these fields.

PROPORTION OF PUBLICATIONS WITH ACADEMIC-BUSINESS COLLABORATION

What it measures

This shows the proportion of research outputs which have at least one business-affiliated and one university- or Crown Research Institute-affiliated author.

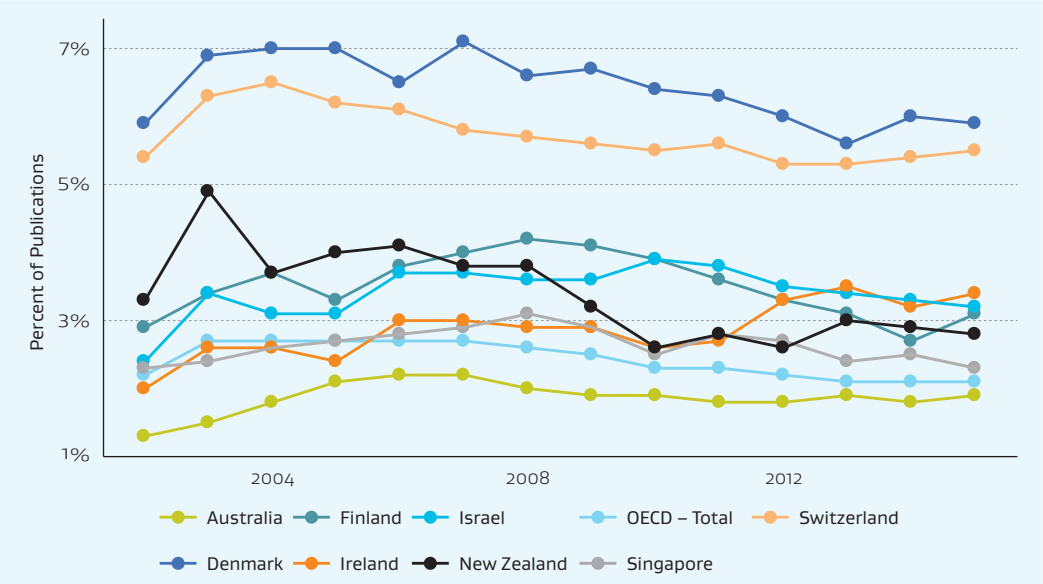
Why it matters

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.

What the data show

Figure 54 Proportion of publications with academic-business collaboration



Just under 3 per cent of New Zealand's publications have academic-business co-authorship.

New Zealand fares better on this indicator than the OECD average and Australia, and on a par with Israel, Ireland, Finland and Singapore. Denmark and Switzerland's rates of academic-business co-authorship are around double New Zealand's.

RESEARCH IN UNIVERSITIES FUNDED BY BUSINESS

What it measures

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

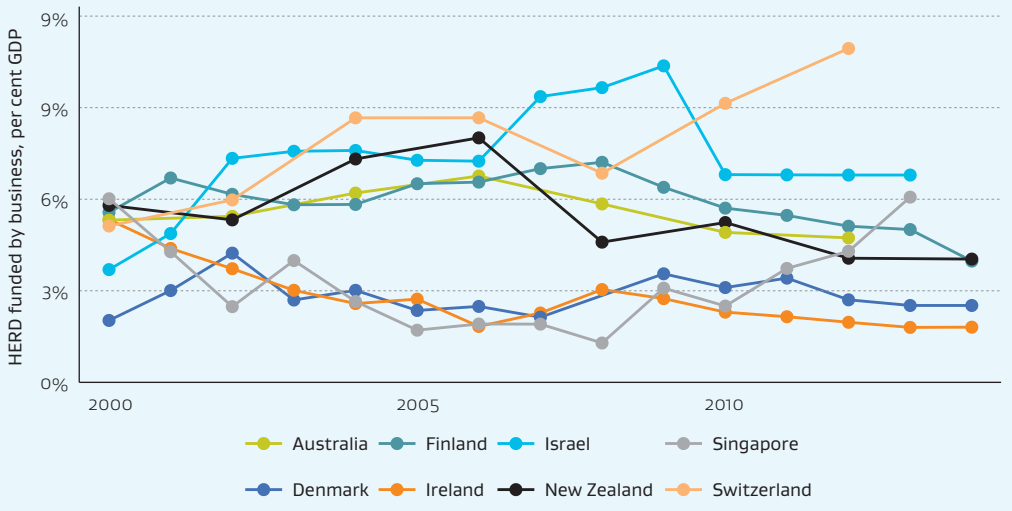
Why it matters

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. In addition, patents from business-funded work receive higher patent citation rates, indicating greater 'knowledge spillover' effects[7].

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

What the data show

Figure 55 Proportion of research in higher education funded by business



Between 4 per cent 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. This decrease is partly a function of increasing public funding, but the dollar value of higher education research funded by business has decreased by 31 per cent ($15m) between 2006 and 2014.

Businesses spend a greater proportion of their R&D funding in the government sector than in the tertiary education sector (primarily Crown Research Institutes). This is to be expected from the more applied research focus of most Crown Research Institutes.

BUSINESSES WITH COOPERATIVE ARRANGEMENTS FOR THE PURPOSE OF INNOVATION

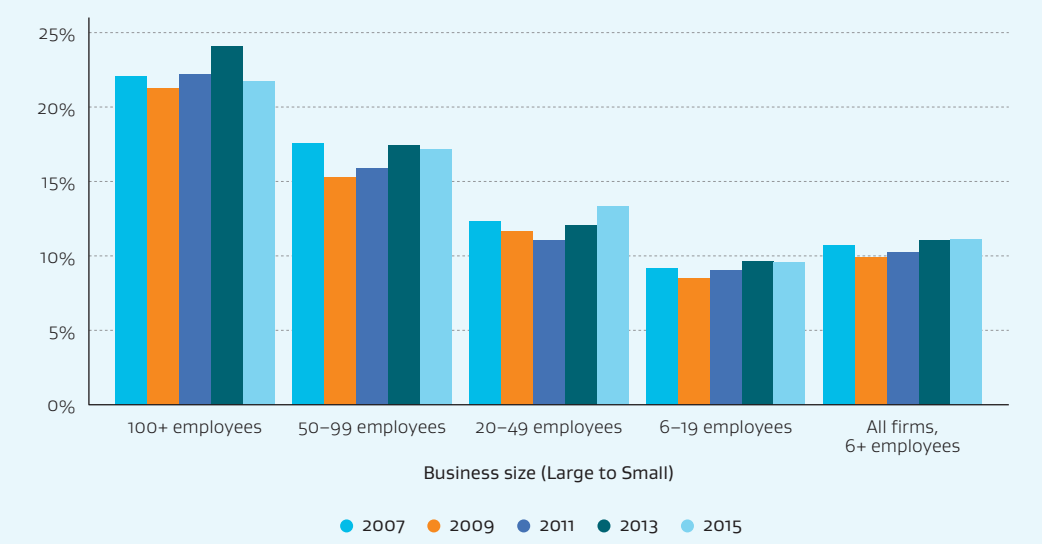
What it measures

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.

Why it matters

The importance of inter-firm cooperation on research is emphasised by theories such as Open Innovation[8]. 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 56 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.

More detailed results from the Business Operations Survey show that suppliers and customers are the primary partners in cooperative arrangements for innovation. Less than 5 per cent of businesses are cooperating with research institutions on innovation – consistent with the results from the indicators 'Proportion of publications with academic-business collaboration' and 'Research in universities funded by business'.

The economic and regulatory environment

Science and innovation activity is not isolated from other economic and societal activity – many factors indirectly affect it. Key factors are the regulatory environment, societal preferences, economic and market structure, geography and infrastructure .

REGULATION AND SOCIAL LICENSE

For research

Scientific research can pose dilemmas for society when the potential benefits come with risks or ethical issues. Examples include medical and other research on people, genetic modification and research that uses or produces hazardous materials.

Health research applications are reviewed by regional Health and Disability Ethics Committees (HDEC), run by the Ministry of Health - if they are within their scope of review. Committees check that proposed health and disability research meets or exceeds established ethical standards. Applications outside the scope of HDEC go through tertiary institution ethics committees.

Ethics review systems vary from one country to another but they are all based on good ethical standards. Like Australia and Canada, our system incorporates indigenous consultation. New Zealand has a conservative approach to vulnerable populations, with the Code of Health and Disability Services Consumers' Rights promoting and protecting the rights of health and disability services consumers. Research on viable human embryos cannot be done in New Zealand.

Research involving genetic modification is controlled in New Zealand by the Environmental Protection Authority under the Hazardous Substances and New Organisms Act. The Act applies a precautionary approach to research and other uses of genetically-modified organisms. Applicants must convince the regulator that the expected positive effects of the activity will outweigh any adverse effects. A 2012 report[9] looked at the factors that influence firms' decisions about innovation with new organisms. It found that economic and market factors (including social acceptance) were the first and most important issues considered, but that regulatory factors are nearly as important, and play a greater role in decision making than for firms innovating in other areas.

For business

New Zealand's regulatory and institutional environment is considered internationally to be very favourable for business investment and productivity growth. We rate highly in terms of property rights and business regulation. The World Bank has ranked us as second internationally for the ease of doing business in 2015 and the easiest place to start a business[10].

In spite of this, New Zealand's labour productivity lags behind other OECD countries, giving rise to what has been called New Zealand's 'Productivity Paradox'. For example, income per capita is more than 20 per cent below the OECD average, when economic settings would predict 20 per cent above the OECD average based what is seen in other countries[11].

OECD modelling has suggested that of the nearly 27 per cent by which we lag the OECD average productivity:

- 3 to 11 percentage points is due to low levels of investment in R&D
- 15 percentage points is due to New Zealand's small size and distance from international markets.

GEOGRAPHY

New Zealand is small and distant from overseas science and innovation centres and markets, but science, innovation and trade are increasingly global in nature. Science and trade help us forge and maintain links with other countries and can expose us to and involve us in cutting edge scientific knowledge and innovation at a global scale.

New Zealand is relatively well connected to international fora and research partnerships, such as the Global Research Alliance on Agricultural Greenhouse Gases. This reflects the world-class nature and standing of some of New Zealand's science.

MBIE's Catalyst Fund supports international science partnerships and MBIE is developing an International Science Strategic Action Plan to be published in early 2017. We need to continue to connect with excellent international science to extend New Zealand's capabilities and gain access to expertise and resources that support innovation. The International Science Strategic Action Plan will signal government's expectations and actions toward these aims.

There is a global trend of both globalisation and agglomeration. Agglomeration means larger concentrations of people, with particular skills, infrastructure and capital. Examples include Silicon Valley and financial services in London. Evidence suggests that innovation is higher in cities and other agglomerations due to: efficient use of infrastructure; more efficient matching between skills, research institutions, products, entrepreneurs, financiers; and greater spill-overs and knowledge sharing[12].

New Zealand's small size, low population density (except Auckland) and distance to global markets pose challenges in either gaining the innovation benefits of agglomeration at home, or connecting easily to overseas innovation centres.

CAPITAL MARKETS

To engage in R&D requires significant investment by firms. Capital markets in New Zealand are typically limited by international standards. The pool of funds available is small, and often these funds are tied up in non-cash assets, limiting their liquidity. The cost of capital, by way of interest rates, is also comparatively high. Work undertaken by the Reserve Bank has concluded that these factors are largely a reflection of the small size of the economy rather than settings that policy can readily impact[13].

Recent government work has focused on overhauling the rules governing capital markets to help support more readily available capital and boost investor confidence. In addition to this, in 2015 the Government developed the Investment Attraction Strategy, which aims to attract:

- foreign direct investment (FDI)
- overseas investment in R&D, and
- high-quality or entrepreneurial investors.

This strategy works to attract 'smart-capital', which is to say, capital that comes with knowledge and skills attached.

LABOUR MARKETS

Science and innovation require an appropriately skilled labour force. The secondary and tertiary education system fares well versus international comparators. Scientists with a wide range of specialisms are developed by New Zealand tertiary institutions, and we successfully attract both students and qualified science, technology and engineering professionals from overseas.

The skills required for innovation can vary widely, from basic science, maths and literacy through to advanced research or engineering skills. In today's increasingly technology-rich work environment, a strong grounding in ICT skills is also critical. In particular, technology businesses need access to high level science, technology, engineering and mathematics skills in order to innovate. For example, OECD estimates have indicated that 43 per cent of innovation in manufacturing is done by people with engineering qualifications[14].

In New Zealand's case, businesses say that difficulties accessing appropriately skilled and experienced people hamper innovation, particularly in the manufacturing, professional, scientific and technical services sector[15]. Developing a workforce with the appropriate skills mix to support business innovation is an ongoing challenge for New Zealand.

INFRASTRUCTURE

New Zealand's distance from markets and the dispersed but highly urbanised population means we rely on resilient energy, telecommunications and transport infrastructure in particular. As part of this there is an important ICT and technology aspect to research and innovation. Current evidence indicates that though we have good ICT infrastructure available compared to OECD averages, New Zealand's use and uptake of IT, particularly in business could be improved[16].

Section 4:

Performance

Progress against the National Statement of Science Investment goals

The National Statement of Science Investment (NSSI) is the Government's 10-year strategy for the science system in New Zealand. It sets out a vision of 'a highly dynamic science system that enriches New Zealand, making a more visible, measurable contribution to our productivity and wellbeing through excellent science'.

It states that by 2025, we want to see:

- a better-performing science system that is larger, more agile and more responsive, investing effectively for long-term impact on our health, economy, environment and society
- growth in BERD to well above 1 per cent of GDP, driving a thriving independent research sector that is a major pillar of the New Zealand science system
- reduced complexity and increased transparency in the public science system
- continuous improvement in New Zealand's international standing as a high-quality R&D destination, resulting in the attraction, development and retention of talented scientists, and direct investment by multinational organisations.
- comprehensive evaluation and monitoring of performance, underpinned by easily available, reliable data on the science system, to measure New Zealand's progress towards these goals.

Publishing this report was one of the actions proposed in the NSSI to improve evaluation and performance measurement in the science and innovation system. The science and innovation data domain plan is a complementary initiative to contribute to the improvement of evaluation and performance measurement in the sector. We expect that when the domain plan is implemented, the insight we can draw from data will begin to greatly improve.

Some data are available that can provide an indication of how far we have progressed towards achieving the NSSI vision, and are set out in the following pages.

A LARGER SCIENCE SYSTEM

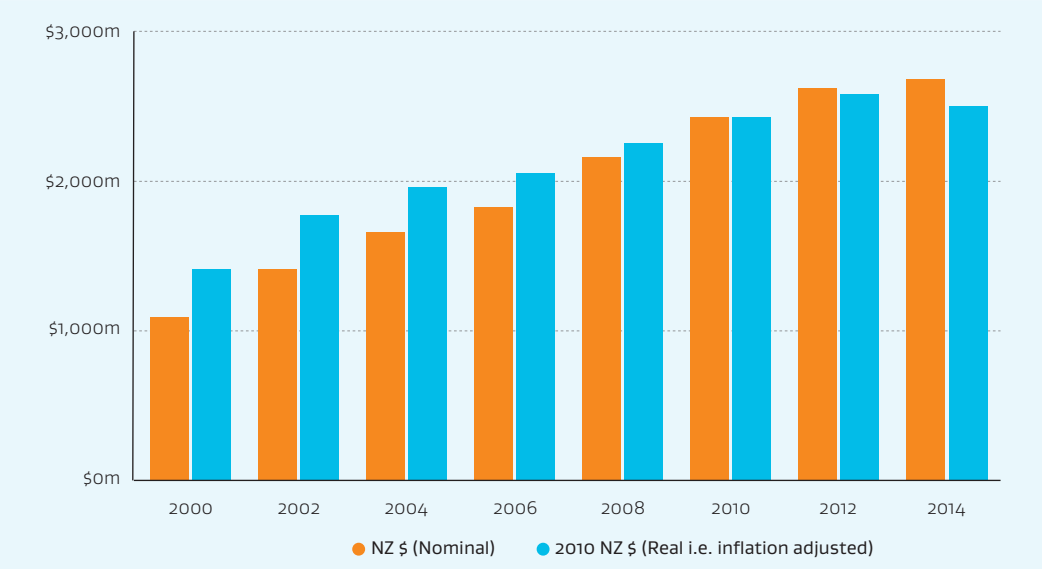
Total Gross Expenditure on R&D (GERD)

This measures expenditure on Research and Development (R&D) across the New Zealand economy. It is the total of expenditure in business, higher education and government.

As noted in Section 2, R&D expenditure has a strong growth trend over the last ten years. It increased by $60m (2.3 per cent, or 1.1 per cent CAGR*) between 2012 and 2014, driven by $52m growth in business R&D.

In real terms (adjusted for inflation), GERD showed a slight decrease between 2012 and 2014.

Figure 57 Total Expenditure on R&D, nominal and real (inflation-adjusted)



GROWTH IN BUSINESS EXPENDITURE ON R&D (BERD) TO WELL ABOVE 1 PER CENT OF GDP

What it measures

This indicator shows business expenditure on R&D (BERD) as a proportion of New Zealand's total domestic product.

Why it matters

The National Statement of Science Investment sets out the goal of raising BERD to well above 1 per cent of GDP by 2025. BERD indicates how much New Zealand businesses are investing to be at the forefront of productivity gains.

* Compound annual growth rate

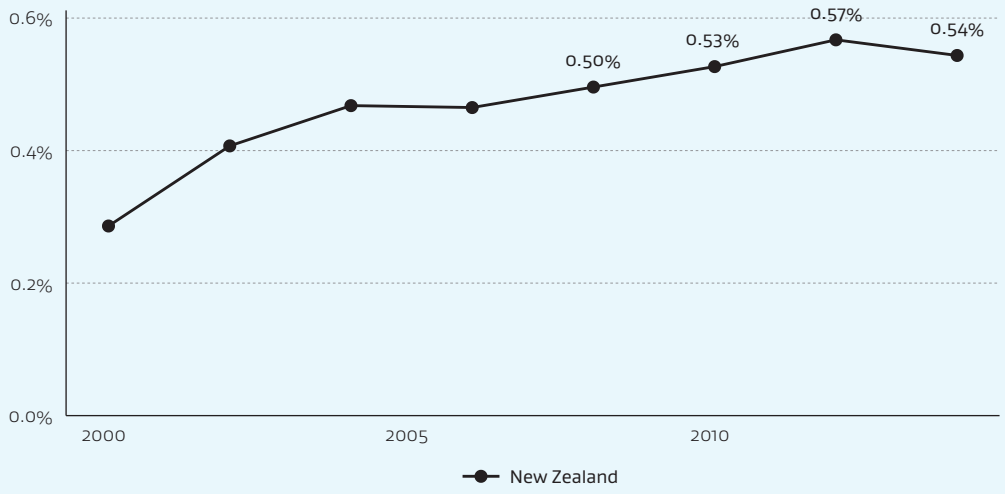
What the data show

In 2014, BERD as a percentage of GDP was low compared to the other Small Advanced Economies. However, the percentage figure disguises significant growth in expenditure in new and emerging industries in New Zealand, in particular computer services, which accounted for 25 per cent of BERD in 2014, up from 19 per cent in 2012.

The data available for 2015 (not shown in Figure 15) suggest that business R&D grew strongly to 0.60 per cent of GDP in 2015. This data point is from a different source (Business Operations Survey) to the rest of the data series (R&D Survey) and is not strictly comparable due to different sampling methodologies. MBIE is developing an annual measure of Business R&D which will be used in future reports.

Over the next 10 years, we expect BERD to rise well above 1 per cent of GDP. This will be assisted by strong policy settings and stable incentives, but also driven by an increasing concentration of high technology businesses in the economy.

Figure 58 Business R&D as a proportion of GDP



CONTINUOUS IMPROVEMENT IN NEW ZEALAND'S INTERNATIONAL STANDING AS A HIGH-QUALITY R&D DESTINATION – FOREIGN INVESTMENT IN R&D

What it measures

This indicator shows levels of foreign investment in R&D that is, the amount invested in R&D in New Zealand by entities overseas, usually businesses. The data are calculated from constant purchasing power parity values.

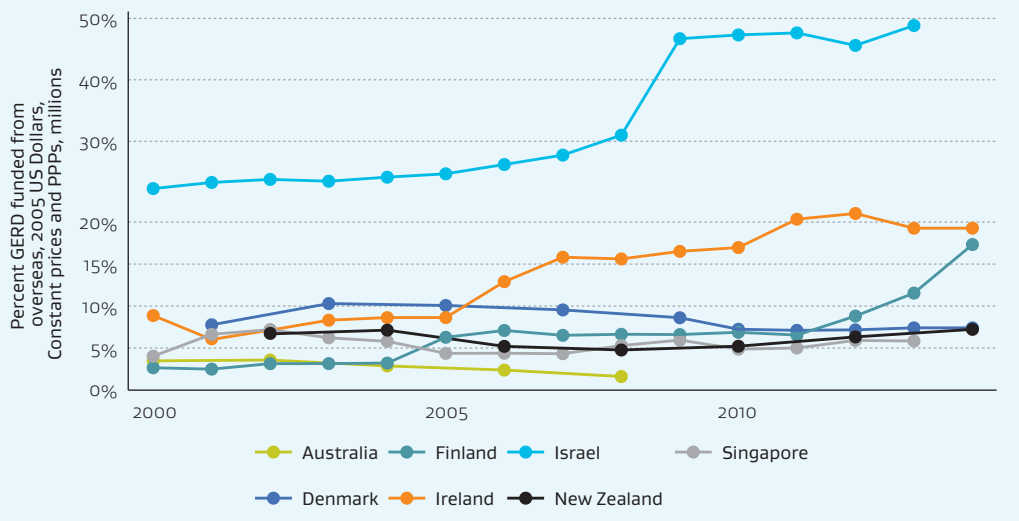
Why it matters

Productive investment from overseas is important to grow the New Zealand economy. It is indicative of how highly valued the New Zealand science system is globally, and to a certain extent how we rate on science quality. New Zealand will also experience other benefits from such investment – for example, the skills and knowledge developed in the domestic science system while working on overseas-funded projects.

What the data show

Israel is a clear outlier in the data below. As a proportion of the science and innovation system, New Zealand's percentage is on a par with Singapore, Denmark and Finland. Foreign investment in New Zealand R&D has grown by 62 per cent since 2007.

Figure 59 Proportion of total R&D funded from overseas

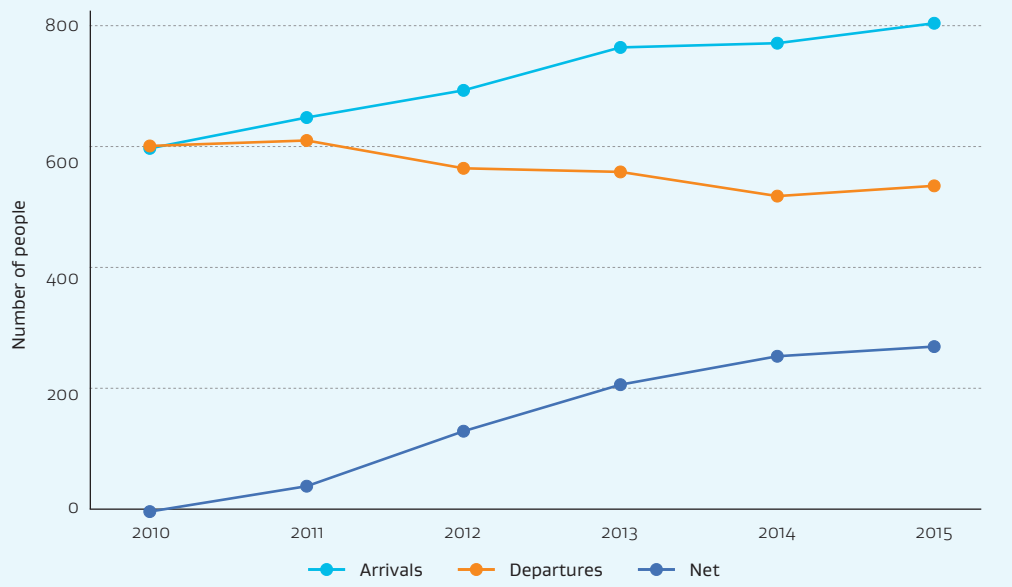


ATTRACTION, DEVELOPMENT AND RETENTION OF TALENTED SCIENTISTS

In terms of developing home-grown science talent, New Zealand students gaining tertiary qualifications in natural and physical sciences at (degree level and above) rose from 3840 in 2008 to 4780 in 2014. This is a slight increase in the share of total qualifications at this level (8.9 per cent to 9.3 per cent). Ministry of Education data reveal that a large portion of these graduates go overseas in the nine years following study: 10 per cent in year 1 rising to 35 per cent in year 9 for Bachelor graduates; 34 per cent in year 1 rising to 41 per cent in year 9 for Doctorates.

However, only a fraction of these students will be working as science professionals in New Zealand or overseas. Also, recent data on long-term and permanent migration of science professionals indicates that New Zealand has been attracting more scientists than are leaving since 2010, and that net inward migration of scientists is increasing (Figure 61).

Figure 60 Inward migration of science professionals



In 2014 Elsevier prepared a study of researcher movements for MBIE. It used publications between 1996 and 2012 to track researchers' movements (based on research institution affiliation) between New Zealand and other countries, as well as the rate of publication and 'quality' of these researchers based on their field-weighted citation impact scores[17].

The study found that the long-term and permanent inflows and outflows of researchers to New Zealand were equal in number and 'quality' (as measured by field-weighted citation impact), indicating no long-term 'brain drain' or 'brain gain'.

Another key finding was that the 51 per cent of active New Zealand researchers were 'transitory' – regularly switching between publishing in New Zealand and other countries. The subset of transitory researchers who were mainly non-New Zealand based (38 per cent of total researchers) were nearly twice as productive and achieved higher field-weighted citation impact than the New Zealand average (1.90 vs 1.76). This indicates that New Zealand is successfully attracting a large pool of overseas transitory researchers who make a substantial and high-quality contribution to New Zealand's research outputs.

MORE AGILE AND MORE RESPONSIVE

There is a recognised risk in science and innovation funding of bias towards proposals with well-known approaches at the expense of novel, riskier options. However, novel approaches are those most likely to give large, long-term payoffs[18].

As stated in the National Statement of Science Investment, the government wants to see a more agile and responsive science system in 2025 so that new areas of research continue to be explored. A dynamic system is also able to respond to the changing opportunities and issues faced by New Zealand in the face of accelerating technological progress and a more interlinked global society.

A recent policy change that will help improve the system's agility and responsiveness is the redesign of the Endeavour Fund (previously the MBIE Contestable Science Fund). Previously proposals were invited to address specific research areas. The redesigned mechanism combined six sector-specific, legacy funds into a single $183m fund in 2016/17, which will increase to over $200m in 2019/20. Research is now investigator-led and funding decisions are focused on the contribution to excellence and potential for impact across economic, environmental and social domains. This should create a more dynamic fund by generating greater contest between investigator-led proposals.

REDUCED COMPLEXITY AND INCREASED TRANSPARENCY IN THE PUBLIC SCIENCE SYSTEM

This report increases the transparency of the science and innovation system by publishing relevant data on funding, outputs and benefits for New Zealand in a single place. This improves public accountability as it shows how public funds have been invested and gives insight on the value for money received, in terms of scientific outputs and the ultimate benefits for New Zealanders. Including projections of four-year science funding by mechanism provides clear signalling for scientists and research institutions of the government's budgetary commitments.

Another recent initiative which supports increased transparency in the public science system is the publication of the Royal Society's guidelines on public engagement for researchers, scholars and scientists.

The purpose of these guidelines is to support the inclusive engagement of stakeholders in research, scholarship and science. The guidelines (consultation draft version) are based on three principles:

- that society benefits from being informed about new knowledge and its application
- that differing contexts of engagement bring different obligations, and
- that acting with professionalism and transparency are necessary to build and maintain public trust.

COMPREHENSIVE EVALUATION AND MONITORING OF PERFORMANCE, UNDERPINNED BY EASILY AVAILABLE, RELIABLE DATA ON THE SCIENCE SYSTEM

MBIE is leading a cross-government effort to improve the data and statistical information on science and innovation in New Zealand. Information and data on the science and innovation system has suffered from a lack of oversight and coordination for some time. This problem has become more acute as the funding landscape has become more complex and calls to demonstrate impact have grown. The result is that institutions and individuals who are part of the science and innovation system cannot obtain some basic information on New Zealand's research profile, the strengths and weaknesses of the research system and opportunities for collaboration. The general public lacks accountability data on how taxpayer money has been spent and the results of that spending. Government agencies lack data to inform investment decision-making and policy settings.

The Science and Innovation Domain Plan sets out a long-term roadmap for improving data on science and innovation in New Zealand. The domain plan is covering funding and expenditure, R&D outputs, people and skills, business R&D and innovation, collaboration, knowledge transfer and commercialisation, infrastructure and costs.

A key action is likely to be the creation of a rich dataset on publicly funded or supported research in New Zealand and that this data be made public, subject to privacy and commercial considerations. As the recommendations of the domain plan are implemented, the data will feed into the Science and Innovation System Performance Report, providing a richer understanding of New Zealand's science and innovation system over time.

Conclusions

Science and innovation create the knowledge and capabilities that will help New Zealand compete economically in a globalised world and address critical environmental and societal issues. We are starting from a good base of a strong tradition of government science, a world-ranked university sector, business-friendly regulatory system and good telecommunications infrastructure. However we face an ongoing challenge of growing or attracting R&D-intensive industry sectors or large, R&D performing firms.

Science and innovation has many parts: researchers and research funders and institutions in the public and private sector; the knowledge created through R&D in New Zealand and overseas; the impacts on the economy, society and environment; and the students who will be the next generation of scientists and innovators. This report has presented data on these parts to provide a picture of the performance of the system as a whole. Key conclusions are listed below.

THE SCIENCE

- New Zealand's research sector is efficient in terms of research outputs (i.e. scientific publications) produced per research dollar.
- This does not seem to be at the expense of average research quality. New Zealand gets more of its papers in the top-10 per cent and top-1 per cent most-cited than the OECD average.
- However, we are behind most other Small Advanced Economies on both the top 10 and top-1 per cent cited research measures, suggesting there is still opportunity to improve on these measures of research quality.
- New Zealand's research effort (in terms of volume of publications relative to the world) does not appear to be optimally matched with the areas in which we produce high-quality research.
- For example, we excel in Engineering, Physics and Astronomy, Computer Science and Energy research (based on publications in top 1 per cent most-cited in those fields), but these are a relatively small share of New Zealand's output (compared with the share these make up of global research).

INNOVATION

- **NSSI goal: business R&D of over 1 per cent of GDP**
  New Zealand's business R&D remains low among OECD countries and Small Advanced Economies. This is driven by economic structure being focused on lower R&D intensity industry sectors, lower R&D intensity within those sectors and a lack of very large firms.
  Progress is slow but steady towards the specific NSSI goal of business R&D of over 1 per cent of GDP (0.47 per cent in 2004 rising to 0.54 per cent in 2014, with an indicative value of 0.60 per cent in 2015). Public support for business R&D is growing in-line with business demand for Growth Grants.
- New Zealand firms report relatively low levels of innovation, at 18 per cent (the proportion of firms reporting sales from new products and services in 2015). Higher rates are seen in manufacturing (27 per cent), ICT (29 per cent), and wholesale trade (36 per cent) but these are a smaller share of the economy than in other Small Advanced Economies.
- New Zealand's patenting rates are low and our published research has relatively little impact on global innovation.
- Developing good measures of public-sector innovation will be a key focus of future reports.

IMPACTS

This report presented stories which traced the impacts of different scientific developments in New Zealand, who was involved, how they were funded, and the results that occurred. These success stories are illustrative only. Future reports will take a more comprehensive approach to science impact assessment – identifying successes but also sampling randomly across funded science projects. This will provide a more robust picture of the overall returns to science and stronger attribution of impacts to particular funding mechanisms.

FUNDING

- The New Zealand science and innovation system is relatively small.
- Total expenditure on R&D across the economy has grown significantly in real terms since 2000 (by around 75 per cent), driven by expenditure in the business sector. Nonetheless, it remains low by international standards (as a proportion of GDP). The largest share of R&D is performed within business (almost half), followed by higher education then government.
- **NSSI goal: Publicly funded R&D of 0.8 per cent of GDP**
  In spite of real spending growth, public funding of R&D has remained roughly constant at around 0.5 per cent of GDP since 2009. Budget 2016 injected a further $410m over four years into public support of science and innovation. Based on current GDP projections, further investment in addition to the new money committed in Budget 2016 is likely to be required to reach the 0.8 per cent of GDP goal.
- Historically, the largest public science funding mechanisms have been the Performance-Based Research Fund, Crown Research Institutes, and MBIE's contestable research funding. Support for business R&D has grown into a major investment area in recent years.
- **NSSI goals:**
  - **Increase support for investigator-led discovery research**
  - **Increase investment in health research**
  - **Support ICT research**
- Budget 2016 investment will drive growth over the next four years in investigator-led research (Marsden +$66m, Endeavour +$114m) and health research (+$97m). Other growth areas based on commitments in previous budgets will be the National Science Challenges and support for business R&D.
- ICT research is likely to receive support through general science and innovation funding mechanisms (e.g. Endeavour, Marsden, university funding and R&D Growth Grants). New Zealand appears to have some niche expertise in Computer Science which could be an opportunity for further investment.

PEOPLE AND SKILLS

- The number of researchers in New Zealand is increasing but remains relatively low compared with other Small Advanced Economies. Business employs the most (non-student) researchers.
- There is a marked gender disparity in many research fields. This seems to be slowly becoming less extreme in some fields (more men in nursing and education research; more women in physics, chemistry and engineering).
- **NSSI goal: attraction, development and retention of talented scientists**
- New Zealand students lag those in other Small Advanced Economies and Australia in science and maths achievement at Year 5, but score similarly to these countries at Year 9.
- The number and proportion of Science, Technology, Engineering and Maths graduates is steadily increasing, but remains low compared to other small advanced economies.
- We are successfully attracting a significant net inflow of science professionals from overseas as permanent or long-term immigrants. Highly mobile, transitory researchers make a particularly high-quality contribution to New Zealand's research outputs.

CONNECTIONS

- The data suggest that key parts of New Zealand's science and innovation system are reasonably well connected.
- Around 87 per cent of science publications involve some sort of collaboration between authors. New Zealand also has strong international science links – international collaboration is seen in over 50 per cent of papers and this is growing. Top collaborating partner countries are the US, Australia and the UK.
- Collaboration of research institutions with businesses is at a comparable level overall to that in other Small Advanced Economies (based on co-authorship and co-funding).

- **NSSI goal: continuous improvement in New Zealand's international standing as a high-quality R&D destination**
- Foreign investment makes up 7 per cent of New Zealand's total R&D investment – comparable to some other Small Advanced Economies. The absolute levels of foreign investment and as a proportion of GDP are relatively low reflecting the small size of New Zealand's science system.

THE FUTURE

Changes are taking place in New Zealand's science system. These are intended to drive progress towards the vision and goals set out in the National Statement of Science Investment. The redesign of the Endeavour Fund and new investment through Budget 2016 are focusing on investigator-led research, including health research. The Government will continue to support growing business R&D. This includes the existing Growth Grants and other Callaghan Innovation mechanisms, as well as new Regional Research Institutes and by increasing the contribution of universities to business entrepreneurship and innovation.

New Zealand is developing a space industry. Rocket Lab is a commercial space launch operator using innovative and disruptive technology developed in New Zealand. This area is likely to continue to contribute to science and innovation in New Zealand, both through the application of downstream technologies such as for environmental research and the development of high-tech manufacturing companies employing highly skilled people.

It is critical to monitor the impact of these and other changes, so that policy can work to improve system performance. The Science and Innovation Domain Plan commits to create a rich dataset on publicly funded or supported research in New Zealand. This will enable a better understanding of the science and innovation system, improved transparency, more evidence-based policy settings and smarter investment decisions. As the recommendations of the domain plan are implemented, the data will feed into future Science and Innovation System Performance Reports.

Section 5:

End notes and reference material

Glossary

The following definitions are used in this report.

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. Note that this includes R&D.

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 exchanges 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.

Small Advanced Economies, **SAEs** – New Zealand, Singapore, Switzerland, Finland, Denmark, Ireland, and Israel.

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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Data sources

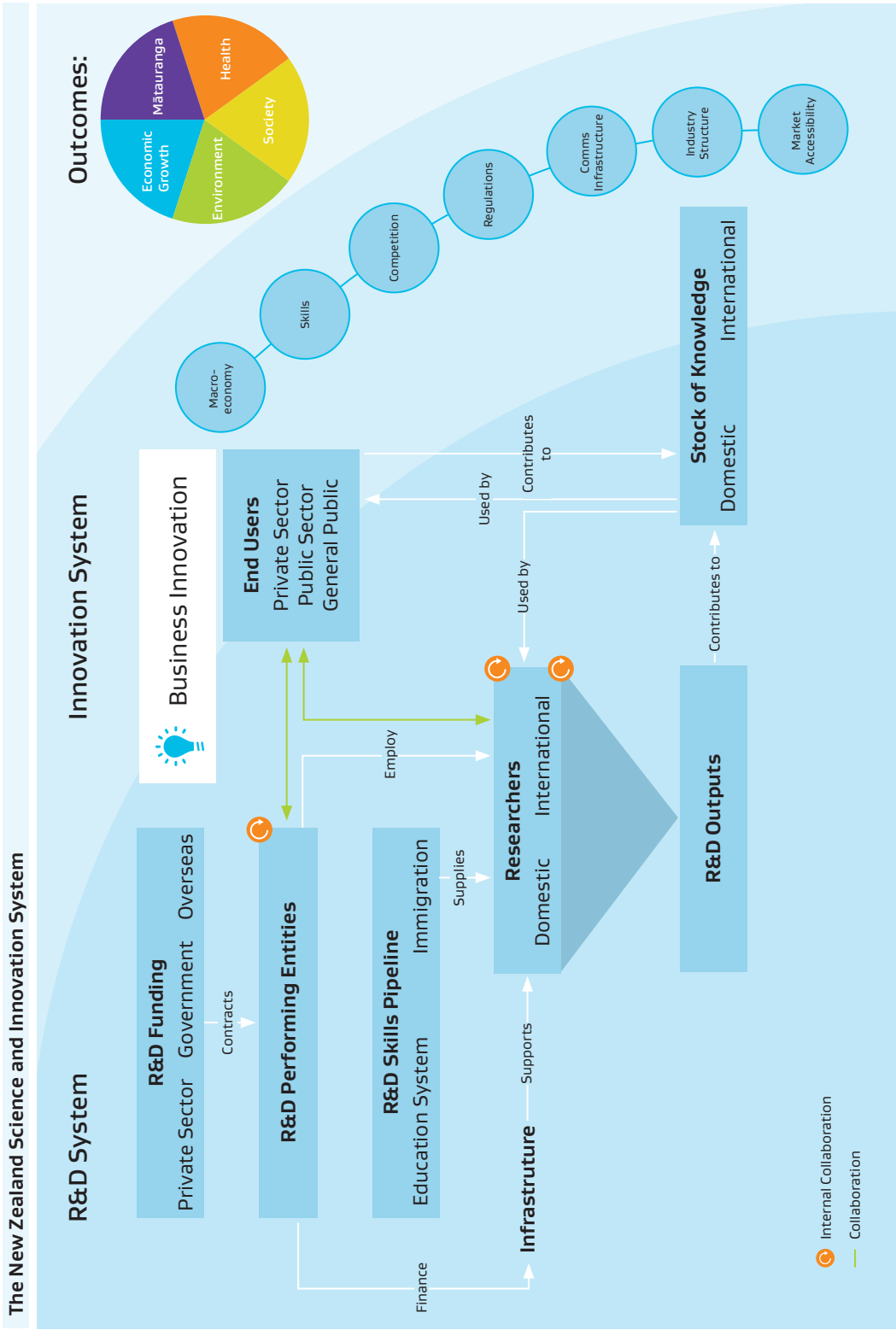
Figure	Description	Source
2	New Zealand's scholarly output	SciVal.com, downloaded 31 May 2016
3	Scholarly output per $m research expenditure	SciVal.com, downloaded 31 May 2016, and OECD MSTI
4	Contribution to research fields by different sectors	Scopus Custom Data, 2010-2014 publications, extracted June 2015
5	Proportion of country publications in top 10 per cent most-cited in their field worldwide	SciVal.com, downloaded 14 April 2016
6	Proportion of country publications in top 1 per cent most-cited in their field worldwide	SciVal.com, downloaded 21 September 2016
7	Field Weighted Citation Impact (FWCI) and volume of publications for New Zealand	Scopus Custom Data, 2010-2014 publications, extracted June 2015
8	Volume of publications and number of citations received in Small Advanced Economies	Scopus Custom Data, 2010-2014 publications, extracted June 2015
9	New Zealand's revealed comparative advantage in research volume and average citation impact	Scopus Custom Data, 2010-2014 publications, extracted June 2015
10	New Zealand's revealed comparative advantage in research volume and publications in top 1% most-cited	Scopus Custom Data, 2010-2014 publications, extracted June 2015
11	Research areas and relationships between Endeavour, Marsden and HRC research, 2008-15	Analysis of MBIE, Royal Society and HRC administrative data using QUID.com
12a	Research areas and relationships between Endeavour research areas, 2008-15	Analysis of MBIE, Royal Society and HRC administrative data using QUID.com
12b	Research areas and relationships between Marsden research areas, 2008-15	Analysis of MBIE, Royal Society and HRC administrative data using QUID.com
12c	Research areas and relationships between HRC research areas, 2008-15	Analysis of MBIE, Royal Society and HRC administrative data using QUID.com
13	How business expenditure on R&D is funded (2014)	Statistics NZ R&D Survey 2014
14	Business expenditure on R&D as a proportion of GDP	OECD MSTI
15	Business expenditure on R&D, nominal and real	OECD MSTI
16	Proportion of businesses reporting innovation and their sector's share of the economy, 2015	Statistics NZ Business Operations Survey

Figure	Description	Source
17	R&D expenditure by industry sector	Statistics NZ R&D Survey 2014
18	Percentage of businesses who engage in R&D and their average spend	Statistics NZ custom data
19	Total R&D spend by businesses in each size bracket	Statistics NZ custom data
20	R&D expenditure as a proportion of GDP, by business size	OECD MSTI
21	Triadic patent families granted per million population	OECD MSTI
22	Proportion of research outputs which are cited by patents	SciVal.com, downloaded 5 September 2016
23	Economic complexity - position in world ranking	http://atlas.cid.harvard.edu/rankings/
24	Total expenditure on R&D as a proportion of GDP	OECD MSTI
25	Total expenditure on R&D, nominal and real	OECD MSTI
26	R&D funding by source and destination, 2014	Statistics NZ R&D Survey 2014
27	Higher education R&D, nominal and real	OECD MSTI
28	R&D performed by government, nominal and real	OECD MSTI
29	R&D growth by sector of performance, nominal NZD	OECD MSTI
30	Public funding of R&D as a proportion of GDP	OECD MSTI; Statistics NZ and Treasury BEFU 2016 (NZ GDP); 2016/17 Estimates of Appropriations (NZ 15/16 estimated GBAORD)
31	Total public support for science and innovation	Collated from Estimates of Appropriations
32	Public funding by mechanism	Collated from Estimates of Appropriations supplemented with departmental forecasts
33	Expenditure on R&D by purpose of research and sector of expenditure, 2014	Statistics NZ R&D Survey 2014
34	Expenditure on different types of research	OECD MSTI
35	Proportion of research expenditure by type of research	OECD MSTI
36	Number of researchers	OECD MSTI
37	Researchers per 1000 employment	OECD MSTI
38	Researchers by sector	Statistics NZ R&D Survey 2014

Figure	Description	Source
39	Proportion of male and female researchers by field, 2006 and 2012	Women in Science: A 2011 Snapshot, Association for Women in the Sciences (2011) www.awis.org.nz/assets/Files/AWIS-Stats-2011-Booklet.pdf; 2012 PBRF Quality evaluation TEC custom data
40	Year five scores on Trends in International Mathematics and Science Study	National Center for Education Statistics http://nces.ed.gov/surveys/international/ide/
41	Year nine scores on Trends in International Mathematics and Science Study	National Center for Education Statistics http://nces.ed.gov/surveys/international/ide/
42	Proportion of School Leavers Achieving at least 14 credits in Mathematics and Sciences at Levels 1-3	Ministry of Education NZQF Assessment within Learning Areas
43	Proportion of New Zealand graduates who are in STEM subjects	World Development Index
44	People completing qualifications in STEM fields	Ministry of Education http://www.educationcounts.govt.nz/statistics/tertiary-education/retention_and_achievement
45	Inward migration of STEM professionals	http://www.stats.govt.nz/infoshare/ Permanent & long-term migration by ctry of residence, occupation (ANZSCO minor) (Annual-Dec)
46	Inward migration of science professionals	http://www.stats.govt.nz/infoshare/ Permanent & long-term migration by ctry of residence, occupation (ANZSCO minor) (Annual-Dec)
47	Post-doctoral researchers by institution in 2015	MBIE post-doc survey
48	PhD graduates produced per year in New Zealand	www.educationcounts.govt.nz
49	Doctoral graduation rate	OECD Statistics
50	The level of public interest in science in New Zealand and Europe	2014 Nielsen survey
51	Proportion of publications with only one author	SciVal.com, downloaded 14 April 2016
52	Proportion of publications with international co-authorship	SciVal.com, downloaded 14 April 2016
53	New Zealand's international collaborations by country	Scopus Custom Data, 2010-2014 publications, extracted June 2015
54	Proportion of publications with academic-business collaboration	SciVal.com, downloaded 14 April 2016

Figure	Description	Source
55	Proportion of research in higher education funded by business	OECD MSTI
56	Businesses that cooperate on innovation	Statistics NZ BOS
57	Total Expenditure on R&D, nominal and real	OECD MSTI
58	Business R&D as a proportion of GDP	OECD MSTI
59	Proportion of total R&D funded from overseas	http://stats.oecd.org/Index.aspx?DataSetCode=GERD_FUNDS
60	Inward migration of science professionals	Statistics New Zealand Infoshare Permanent & long-term migration by ctry of residence, occupation (ANZSCO minor) (Annual-Sep)

Appendix 1


The New Zealand Science and Innovation System
R&D System
Innovation System
Outcomes:
Economic Growth
Mātauranga
Health
Environment
Society
Macro-economy
Skills
Competition
Regulations
Comms Infrastructure
Industry Structure
Market Accessibility
R&D Funding
Private Sector
Government
Overseas
Contracts
R&D Performing Entities
Business Innovation
End Users
Private Sector
Public Sector
General Public
Used by
Contributes to
Stock of Knowledge
Domestic
International
Employ
R&D Skills Pipeline
Education System
Immigration
Supplies
Researchers
Domestic
International
Used by
Contributes to
R&D Outputs
Finance
Infrastruture
Supports
Internal Collaboration
Collaboration

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