New Zealand's research workforce

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Authors:
Amelia Cordwell
Nikki Wilkinson
Edward Abraham
Katrin Berkenbusch

DRAGONFLY
Data Science

PO Box 27535, Wellington 6141
New Zealand
dragonfly.co.nz

Cover Notes

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EXECUTIVE SUMMARY

This study is part of the multi-year programme "Te Ara Paerangi–Future Pathways" by New Zealand's Ministry for Business, Innovation and Employment (MBIE). Part of the Te Ara Paerangi programme is a review of how research in this country is currently being organised and funded. This study supports this review by providing an analysis of the New Zealand research workforce over time, using existing data. The latter included bibliographic records of academic publications from the open-source database OpenAlex that were used as a proxy for academic research employment. Other sources of information were global population data from The World Bank, New Zealand data from Education Counts, and data from Stats NZ. Based on these data, the analysis focused on demographics of university graduates (studying towards a Doctor of Philosophy, PhD), and their retention and career progression in the New Zealand research workforce across different organisations and disciplines. It included comparisons with the research workforce in Australia, Ireland, and Singapore.

There were approximately 18,029 active publishing researchers in the New Zealand workforce in 2019. Their affiliations were predominantly from tertiary institutions (11,893 researchers), followed by healthcare organisations (1,458 researchers), crown research institutes (CRIs; 1,448 researchers), and other organisations (e.g., independent research organisations or individuals and private companies; 647 researchers). A considerable number of New Zealand authors had an unknown affiliation (e.g., 2,586 researchers in 2019), resulting from insufficient information about author affiliations or from errors in the OpenAlex database.

There was an increase in the New Zealand research workforce from 2010, when there was a total of 12,297 actively-publishing researchers in the country. The number of actively-publishing researchers grew at an average annual rate of 4.3%. The average annual rate of increase in the research workforce was similar at tertiary institutions and healthcare organisations (4.7 and 4.9%, respectively), whereas it was low for CRIs (0.9%). The growth of New Zealand's research workforce was slower than that in Australia, Ireland, and Singapore in the past ten years.

Trends in the number of entrants to the research workforce included a (three-fold) increase in the number of PhD graduates between 2003 and 2020. Recent increases (i.e., within the last ten years) were largely determined by PhD students originating from overseas. These trends were evident across all research fields. The introduction of the Performance Based Research Fund in 2003, and equal access to PhD studies for international students in 2005 led to more than double the number of PhD completions each year; however, the number of academic full-time equivalent (FTE) staff at universities remained relatively constant over this period. The number of Māori PhD graduates remained largely unchanged since 2010, whereas the proportion of Māori graduates decreased from 6.4% in 2004 to 3.8% in 2019.

In contrast to the overall increase in graduates, there was no concomitant increase in FTE staff roles at universities, representing a mis-match between PhD graduates and academic employment opportunities. This aspect was reflected in the lower retention of PhD graduates in the New Zealand research workforce in recent years, evident in a decreasing proportion of PhD graduates continuing to actively publish within five years of their graduation. This finding was the same for both domestic and international students, and appeared to be linked to researchers leaving academic publishing.

The current analysis approach used publication records to characterise New Zealand's research workforce. Based on the OpenAlex data and New Zealand data subsets identified here, potential future analyses include investigations of collaboration patterns within New Zealand, and of potential effects of changes in government policy, and assessing aspects pertaining to precarity and career progression by research field and research organisation. Although the current study was limited to researchers who actively publish academic papers, it is acknowledged that the New Zealand research workforce also contains a proportion of researchers who do not disseminate their research findings through academic publications. Examples include researchers who conduct commercially-sensitive studies or disseminate their findings through other forms of written outputs (e.g., conference proceedings).

1. INTRODUCTION

The multi-year programme "Te Ara Paerangi–Future Pathways" by New Zealand's Ministry for Business, Innovation and Employment (MBIE) is focused on the future of New Zealand's research system (Ministry for Business, Innovation & Employment 2022). Part of this programme includes a review of how research is currently being organised and funded. For this review, Dragonfly Data Science was commissioned by MBIE to provide an analysis of the New Zealand's research workforce, based on existing data.

New Zealand is a small advanced economy, but has low private investment in research and development: there is less than 50% of the funding invested on average in other OECD (Organisation for Economic Co-operation and Development) countries (New Zealand Productivity Commission 2021). Similarly, New Zealand has a low patenting rate and low overall productivity compared with other OECD countries (New Zealand Productivity Commission 2021). Increases in both these metrics have been correlated with increased scientific output (Clancy 2022). Scientific output is frequently measured in the form of published peer-reviewed papers that disseminate new research findings in domain-specific journals.

The general structure of a scientific research career is based on undergraduate studies at a university, followed by supervised research periods as a Masters or Doctor of Philosophy (PhD) student. An important requirement of a PhD degree is original research that makes "a significant contribution to the advancement" of the research field (e.g., University of Otago 2022); this requirement usually includes the publication of at least one peer-reviewed paper in an academic journal. Following completion of PhD study, employment options include post-doctoral positions—a temporary position as an early-career researcher—or a permanent research position either at a university or at a research institution. Once a PhD graduate has secured a position at a university, they begin teaching and typically also supervise graduate students. This career path includes the sharing of knowledge gained through publishing in domain-specific journals, which is an important part of career progression in an academic context.

In New Zealand, over half of the current research workforce has achieved a PhD degree (Royal Society Te Aparangi 2020). Part of this relatively high number of PhD graduates may be related to changes in the New Zealand research system since its inception. Initially, the Department of Scientific and Industrial Research (DSIR) was formed in 1926 to conduct research directed by the government. This department was subsequently split into 10 Crown Research Institutes (CRIs) in 1992, some of which have since then

merged. The CRIs were initially funded through a split of 90% contestable and 10% block funding (Upton 2010); however, the proportion of block funding has subsequently increased, and CRIs are currently supported by the Strategic Scientific Investment Fund (SSIF). For tertiary institutions, the Performance Based Research Fund (PBRF) was introduced in 2003, replacing research funding that was based on the number of enrolled students. The PBRF provides financial incentives for tertiary institutions to achieve research "excellence" and financial rewards based on the number of research Masters and PhD students that are enrolled and graduating.

In addition, university fees for international PhD students were reduced in 2005 to be the same level as fees for domestic students. At the same time, partners of international PhD students obtained the right to work in New Zealand, and school fees for their children were reduced to be the same fee as for domestic pupils. The reasons for these changes were the government's intent to retain top international students in New Zealand, as part of its commitment to "address skill shortages, to upskill [New Zealand's] workforce in general and further develop innovation in the New Zealand economy"' (Mallard 2005b). This approach was also considered to have "direct benefits to universities" because it would "raise the quality and output of academic research" (Mallard 2005a). In this context, a recent survey found that 56% of early-career researchers working in New Zealand were born overseas, with 73 to 90% wishing to remain in New Zealand long-term (Simpson et al. 2022).

Early-career opportunities for PhD graduates include post-doctoral positions, such as fellowship provided under the previous New Zealand Science & Technology post-doctoral fellowship scheme; this scheme was funded by the government between 1993 to 2009, and awarded grants to PhD graduates to continue their careers in New Zealand (Hendy 2010). On average, 28 fellowships of two or three years were awarded each year. In 2010, this scheme was discontinued and replaced by the Rutherford Discovery Fellowships. In the 2022 round, the latter fellowships will support 10 researchers for a period of five years. To qualify, researchers need to have at least three years of research experience following their PhD study (Royal Society Te Apārangi 2022); however, there are currently no national fellowship schemes in New Zealand for financially supporting researchers in the first three-year period post-PhD. In addition, there has been a significant increase in the cost of hiring a post-doctoral researcher, compared with awarding PhD scholarships, further limiting early-career opportunities for PhD graduates (Gaston & Hodgekiss 2020).

At the same time, there has been a significant increase in the number of PhD graduates in the last 20 years, and the majority of these graduates aim to pursue an academic research career (Woolston 2019, Oldfield et al. 2022, Simpson et al. 2022). For example, 66% of the 188 PhD students surveyed in New Zealand in the Precarious Academic Work Survey wish to pursue an academic career (Oldfield et al. 2022). Similarly, 61% of the 21 New Zealand PhD students included in the 2019 Nature Survey indicated that their first career choice was academia (Woolston 2019). As the number of new PhD graduates greatly exceeds the number of academic roles globally, there are increased competition and reduced chances of early-career researchers to publish their research and develop their research career (Milojević et al. 2018, Larson et al. 2014). In New Zealand's research workforce, there have been increasing concerns about stress, burn out, and precarity, extenuated by the COVID-19 pandemic (Royal Society Te Aparangi 2020, Sedgwick 2021).

Furthermore, women, Māori, and Pasifika graduates are under-represented in the academic and general research workforce (McAllister et al. 2022). Increases in the number of PhD graduates from these demographic groups have not led to significant increases in their representation in the research workforce overall (McAllister et al. 2019, Patterson et al. 2020). For example, in the period between 2012 and 2019, there was no statistically significant increase in university professors who were either Māori or Pasifika (McAllister et al. 2019, Patterson et al. 2020). Additionally, women, Māori and Pasifika researchers are less likely to be promoted than their male counterparts of different ethnicity (McAllister et al. 2020).

Within this background of New Zealand's research environment and workforce, the present study analysed bibliographic data to characterise New Zealand's research workforce and investigate its size, career progression, international movements, and career outcomes.

2. METHODS

The current study used bibliographic publishing records as a proxy for academic research employment. This proxy was based on the assumption that active academic researchers are also active in academic publishing, although this assumption may not be applicable to all researchers; for example, researchers working in commercially-sensitive research environments or for commercial companies may not publish their findings. Similarly, written scientific outputs from researchers at CRIs frequently include client reports instead of primary-literature publications. In addition, the frequency and type of publication vary across research fields. Examples include researchers in the humanities who are likely to publish book chapters instead of research papers, and conference proceedings that are an important output in some sub-fields of computer science and engineering.

Bibliographic data were sourced from the OpenAlex database (Priem et al. 2022). Additional sources of information were global population data from The World Bank[1], New Zealand-specific data from Education Counts[2], and data from Stats NZ Infoshare[3].

These data were analysed to provide information of the New Zealand research workforce over time. The analysis focused on the demographics of PhD graduates and on the research workforce across different organisations and disciplines.

2.1 Bibliographic data

The open-source database OpenAlex is the successor to Microsoft Academic Graph, and contains global bibliographic data. OpenAlex also integrates data from sources such as Open Researcher and Contributor Identifier (ORCID), Crossref, and arXiv (Priem et al. 2022). For each item of scholarly publishing, OpenAlex collects details on authorship and author affiliations. It uses a natural language processing approach to identify concepts that make up the topic of the paper. Authors are identified and distinguished based on their name, publication records, citation records and, where available, their

[1] https://data.worldbank.org/
[2] https://www.educationcounts.govt.nz/
[3] https://www.stats.govt.nz/tools/stats-infoshare

ORCID (Priem et al. 2022). Author affiliations are provided as a string, which OpenAlex processes and disambiguates to refer to an institution object (e.g., "Department of Physics, University of Auckland" and "UoA" would both link to the canonical object of the University of Auckland).

Data in the present study were restricted to items with Digital Object Identifier (DOI). Affiliation records were used as a proxy for research employment. If an author has published a paper with an organisation's affiliation in a given year, they were considered an active researcher in that organisation. This linking is not necessarily representative of exact employment situations, because it includes students studying towards research degrees, and researchers temporarily based at an organisation or on sabbatical. In addition, this approach misses research staff in CRIs or private companies who are not publishing their research.

OpenAlex uses machine learning to identify the concepts associated with the published research based on paper titles, journal titles, document types and abstracts. The OpenAlex system is hierarchical with broad fields (e.g., physics, history) given a level of 0, and five levels of nested sub-fields. Here, the top level fields were modified in some figures by associating them with a grouped field.

For publication records contained in the OpenAlex database, the total number of publications was relatively small until the early 2000s, when it increased markedly (Figure 1). Similarly, the proportion of articles including at least one affiliation for an author with a known ORCID increased over time, but this increase was more gradual.

Considering authors with affiliations in New Zealand, the proportion of publications that included affiliations followed a similar trend to that of publications by ORCID authors overall. This proportion was higher than that for all publications within the OpenAlex database. This proportion and average publishing trends were used to calculate the number of authors for a country or institution affiliation that would have otherwise been missed in a particular year (see Appendix A for details).

2.1.1 Author disambiguation

Because OpenAlex is a relatively recent bibliographic database, there are currently few publications that analyse its veracity and coverage. To assess the quality of its method for distinguishing authors, OpenAlex was compared with the ORCID dataset and a computer science bibliographic database (dblp; see dblp.org). The latter database has been recognised for its reliable disambiguation of author names (Kim 2018). This assessment tested OpenAlex against the author identifiers defined by ORCID and by the dblp database. It determined how reliably a cluster can be attributed to exactly one author (best precision, P_{best}) and how reliably an author can be attributed to exactly one cluster (best recall, R_{best}) (Tekles & Bornmann 2020). The F1 score is the geometric mean of these two measures. For this assessment, four comparison datasets were used to define the correct clustering and the test subset of the OpenAlex data. These datasets were: the publication records from the ORCID database; the latter records from ORCID where the ORCID author information was not contained inside OpenAlex; the entire dblp dataset; and dblp dataset excluding any ORCID data. (OpenAlex uses ORCID as part of tits disambiguation of author name.)

The assessment revealed that OpenAlex operates with high precision and 90%

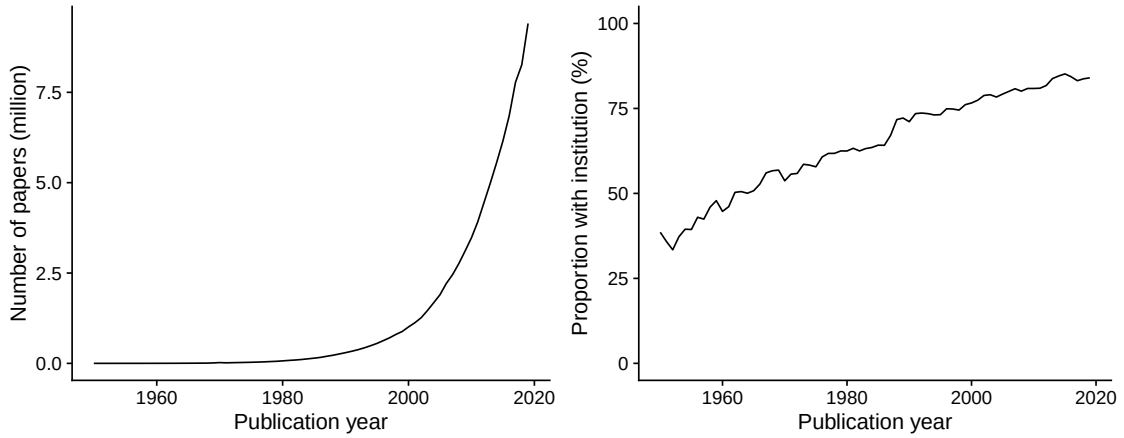

Figure 1: Summary of bibliographic data from the open-source database OpenAlex over time. Total number of publications in the OpenAlex dataset, and proportion of papers published by authors with an Open Researcher and Contributor Identifier (ORCID) and that include the author's institutional affiliation. (Source: OpenAlex)

recall in its "worst-case scenario" (Table 1). The lower recall may have the effect of underestimating the lengths of some careers, and indicates that the OpenAlex dataset may have some small authorship clusters representing a subset of an author's publications. Using ORCID as part of OpenAlex's own matching resulted in 100% precision, but OpenAlex still performed with high precision (over 98.6%) when matching authorship records without known ORCID. Based on this assessment, the author disambiguation by OpenAlex was considered to be sufficiently reliable for analysing research careers in this study.

2.2 Research career history

An author's publication record was used to define their approximate research career history. All authors with a publishing record starting in the same year were considered a cohort. These authors were tracked in each subsequent year until 2022. For each author, the data collation included the number of publications authored each year,

Table 1: Performance metrics for assessing the disambiguation of author name by the OpenAlex bibliographic database. Comparison datasets were publication records from the ORCID (Open Researcher and Contributor Identifier) database, a subset of these data where the ORCID author information was not included in OpenAlex, the computer science bibliographic database dblp (dplp.org), and the dblp dataset excluding any ORCID data. Evaluation metrics were best precision (P_{best}), best recall (R_{best}), and best F1 score (Tekles & Bornmann 2020).

	P_{best} (%)	R_{best} (%)	$F1_{\text{best}}$ (%)
ORCID	100.0	96.3	98.1
ORCID not in OpenAlex	100.0	91.9	95.6
dblp	98.0	90.8	94.3
dblp (no ORCID)	98.6	89.5	93.8

the proportional shared authorship count, and the dominant field of the publications. For each year, authors were considered to be active in the country listed on the first publication of that year. Authors were considered to have left academic publishing in the year of the last recorded publication.

The affiliation data were used to identify authors who were active in a given sector in a year. Known New Zealand institutions were grouped into four categories: CRIs, tertiary institutions (e.g., universities, polytechnics), healthcare organisations (hospitals and medical testing companies), and "other" (e.g., government departments, non-government and independent research organisations). For publications with an identified New Zealand affiliation but without specific detail (e.g., an affiliation string "Wellington, New Zealand"), the institution was classified as unknown. Publications without an affiliation were not included here. Because missing affiliation data depended on time, the overall counts of authors by affiliation were adjusted to account for this aspect.

An author's country of academic origin was considered to be the country of their first publication. Similarly, academic age or years of experience was considered to be the time period (years) since their first publication. Although this information does not link to the citizenship or age of an author, it likely provides information of the author's country of PhD study and of the time period since completion of the PhD. The use of publication year as a a proxy for academic activity may introduce a temporal bias, because it can take a number of years between a research activity and the publication of its findings. Authors with only a single publication were considered transient (and their academic age would remain zero).

2.3 Data analysis

Variations in attrition of publishing authors were statistically assessed using mark-recapture analysis (Laake et al. 2013). For this analysis, a publication record in a year was considered an "observation" of an author. The continuation of an author in the research workforce across years was estimated as "survival", Φ, and the probability of observing an author (or academic researcher) in a year based on their publications, p.

Models were fitted separately for each cohort, with the assumption that survival depended on academic age, and that the observation probability depended on both the primary field of study of the researcher and the year. This assumption provided the model with flexibility to account for the increasing number of publications with time, and for variations in publication rate between fields. The publication rates directly affect the observation probability. The model was fitted using maximum-likelihood methods. The publication history of an individual author was not included. The model was fitted on data up to 2021; however, the model showed evidence of a fall off in recent years that was likely caused by the right-censorship of the data. For this reason, model results presented here are based on model parameters restricted to the period before 2019.

The results from the analysis of bibliographic data from New Zealand were compared with findings from Australia, Ireland, and Singapore.

3. RESULTS

The analysis of scholarly publications by researchers provided information on different aspects of the New Zealand research workforce across disciplines. Using the number of publications as a proxy for research activity also allowed an assessment of PhD graduates, their career paths, and their retention in the research workforce over time.

3.1 New Zealand's research workforce

In 2019, there were approximately 18,029 actively-publishing researchers in New Zealand (Figure 2). The majority of these researchers were affiliated with tertiary institutions, with about 11,893 actively-publishing researchers based at tertiary organisations. There were also 1,458 researchers affiliated with healthcare organisations, 1,446 researchers affiliated with CRIs, and 647 researchers working at other organisations (for example, independent research organisations or individuals, and private companies). There was a considerable number of New Zealand authors with institution type "Unknown"; e.g., in 2019, there were about 2,586 authors in this category. These records resulted from insufficient information about author affiliation or from errors in OpenAlex that led to affiliations that were associated with organisations outside of New Zealand. Further processing of affiliation data may reduce the number of unknown affiliations. The bibliographic data align with estimates from other sources. These sources include a workforce report by the Royal Society Te Apārangi, which estimated that there were around 18,000 active researchers in New Zealand in 2016 (excluding graduate students) (Royal Society Te Aparangi 2020). Other estimates were around 10,300 university-based researchers in 2019, around 2000 researchers at CRIs in 2020, and around 1000 researchers at independent research organisations in 2020.

The total number of actively- publishing researchers in 2019 increased from 12,297 in 2010, corresponding with a 4.3% average annual growth rate in the number of researchers during this period. The number of researchers at tertiary and healthcare institutions increased at a similar rate (4.7%, and 4.9%, respectively). In contrast, the number of actively-publishing researchers affiliated with CRIs remained relatively constant, increasing by an annual average of 0.9% from 2010 to 2019.

Research fields were the most diverse across publications from researchers at tertiary institutions. Authors associated with CRIs published mostly in life sciences and physical and chemical sciences. In comparison, authors affiliated with healthcare organisations published almost exclusively on medical topics.

The academic age (i.e., years of experience) of researchers increased over time across the different organisation types (Figure 3). This increase was the fastest amongst researchers at CRIs, which may have been related to an overall lack of growth in this workforce, a comparatively low proportion of postgraduate students, and low turnover. Across organisations, there was an increase in the proportion of researchers whose first publication had an international affiliation (Figure 4). This increase was the smallest in the healthcare sector.

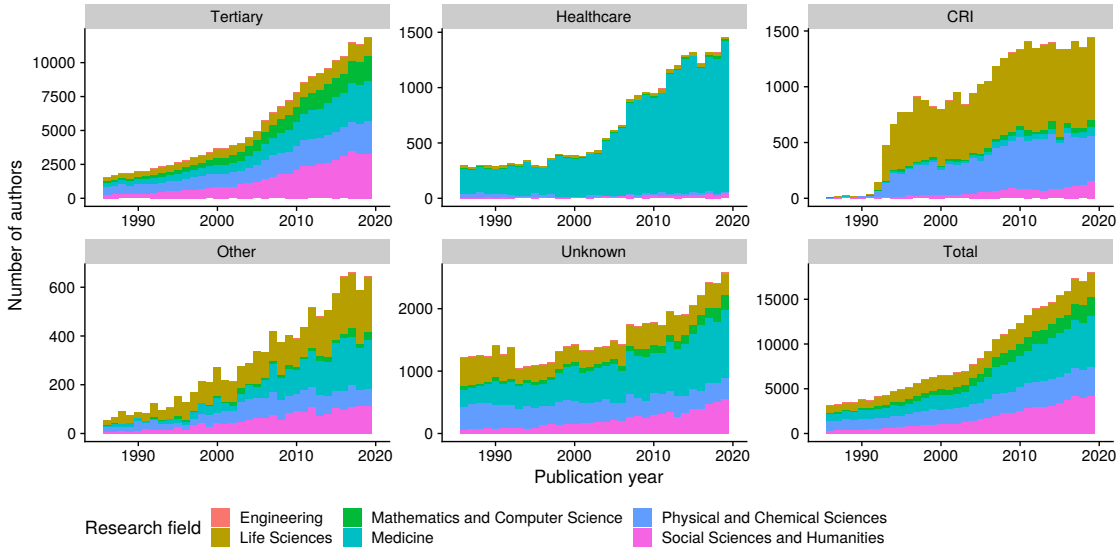

Figure 2: Number of actively-publishing researchers in the New Zealand research workforce by affiliation and by most common field of study (Source: OpenAlex). The total number of authors was adjusted to account for publications with missing affiliation information. (Please note different scales on y-axes.)

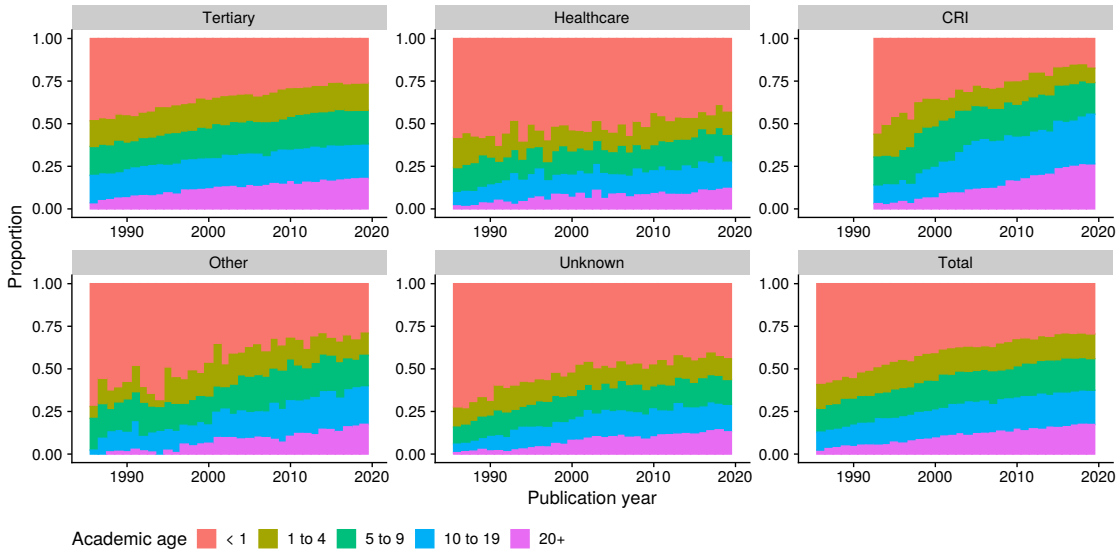

Figure 3: Academic age (years of experience) of actively-publishing researchers by organisation, as time since their first publication (Source: OpenAlex). Organisations were grouped as crown research institutes (CRIs), tertiary institutions, healthcare organisations, and "other" (e.g., government departments, non-government and independent research organisations).

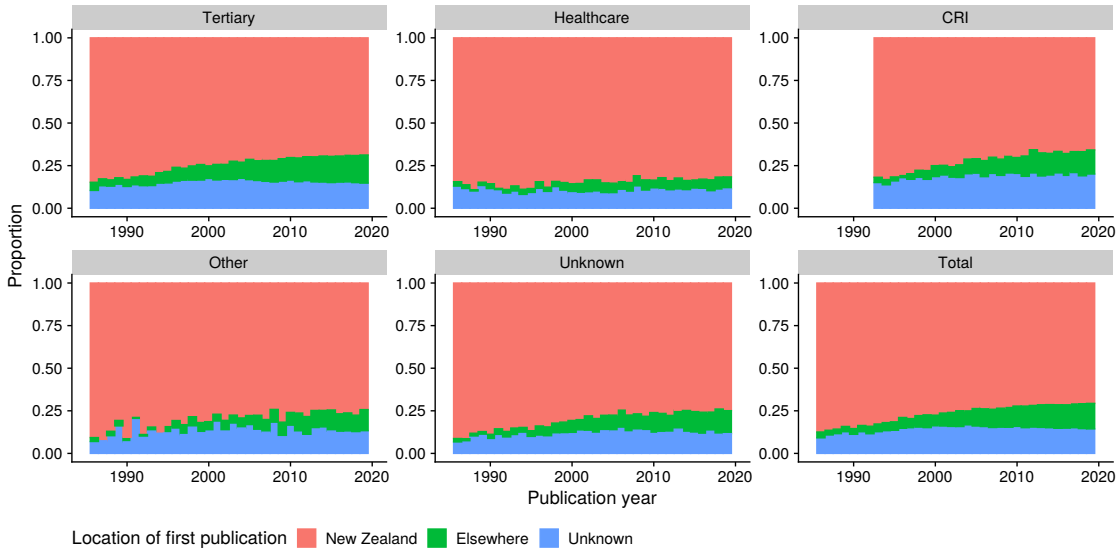

Figure 4: Proportion of actively-publishing New Zealand researchers with their first publication afilliated with an organisation in New Zealand or elsewhere (Source: OpenAlex). Organisations were grouped as crown research institutes (CRIs), tertiary institutions, healthcare organisations, and "other" (e.g., government departments, non-government and independent research organisations.

3.2 International workforce comparison

In an international context, the research workforce (per million people) in New Zealand grew slower in the past ten years than the respective workforces in Australia, Ireland, and Singapore (Figure 5). Between 2010 and 2019, the number of publishing researchers per million people in New Zealand grew from 2858 to 3591 researchers, an annual average increase of 2.6%. In contrast, the number of publishing researchers per million people in Singapore grew from 3343 to 4812 academic authors, an annual average increase of 4.1% over the same period.

In 2000, New Zealand had a similar number or actively-publishing researchers per million people as Singapore (1748 researchers for New Zealand, compared with 1754 researchers for Singapore), and had more actively-publishing researchers per million people than Ireland. Nevertheless, by 2019, New Zealand had fewer researchers per million people than any of the comparison countries. Although the number of actively-publishing researchers per million in New Zealand people increased, it grew at a slower rate than in the comparison countries.

Comparison of research fields across countries showed that during 2019, New Zealand had the lowest number of researchers per million people in medicine, mathematics and computer science, and physical and chemical sciences. In 2019, New Zealand had around 1036 researchers per million people actively publishing in medicine, which was less than half the number in Ireland (2133 researchers per million people). There were 606 researchers per million people actively publishing in physical and chemical sciences, which was less than half the number in Singapore (1298 researchers per million people). There were 425 researchers per million people actively publishing in mathematics and computer science, which was less than half the number in Singapore (916 researchers per million people). New Zealand had a higher intensity of researchers actively publishing

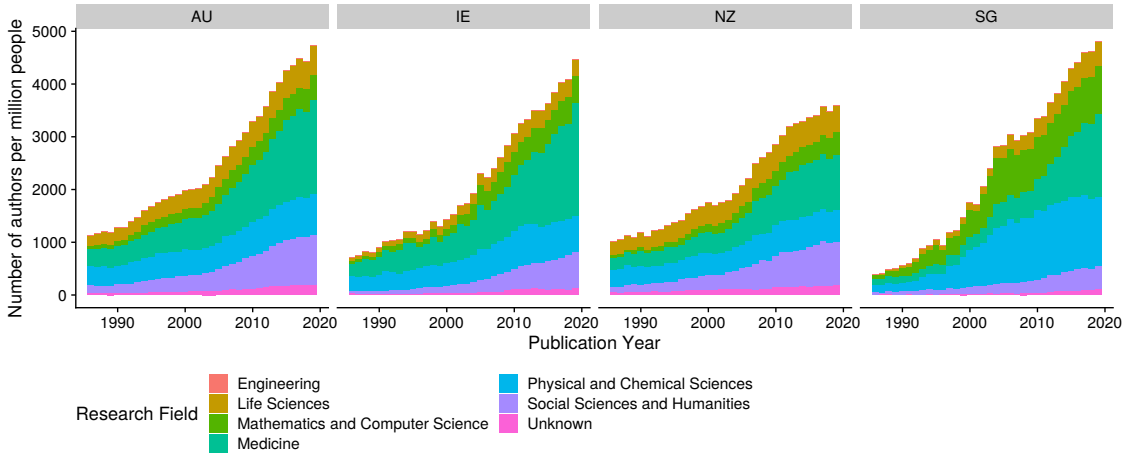

Figure 5: Number of actively-publishing researchers per population size (million people) by country. Publications were distinguished by research field, the country comparison included Australia (AU), Ireland (IE), New Zealand (NZ), and Singapore (SG) (Source: OpenAlex, World Bank population data).

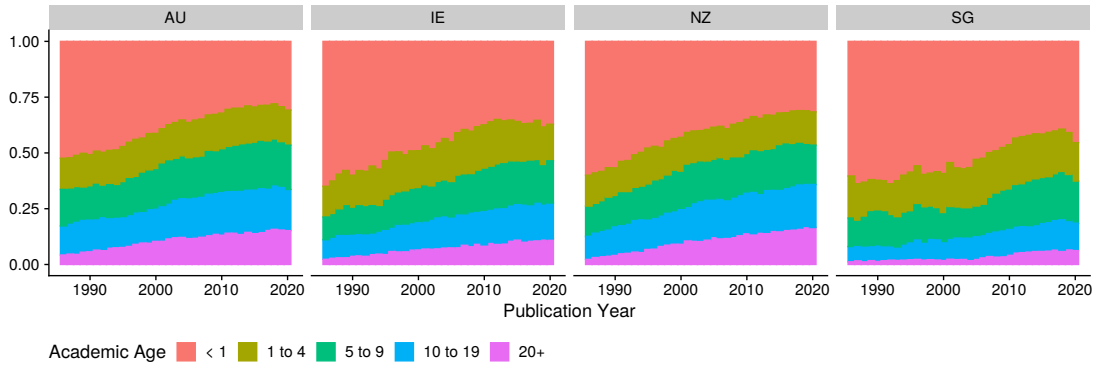

Figure 6: Academic age (years of experience) of actively-publishing researchers by country, as time since their first publication (Source: OpenAlex). Countries were Australia (AU), Ireland (IE), New Zealand (NZ), and Singapore (SG).

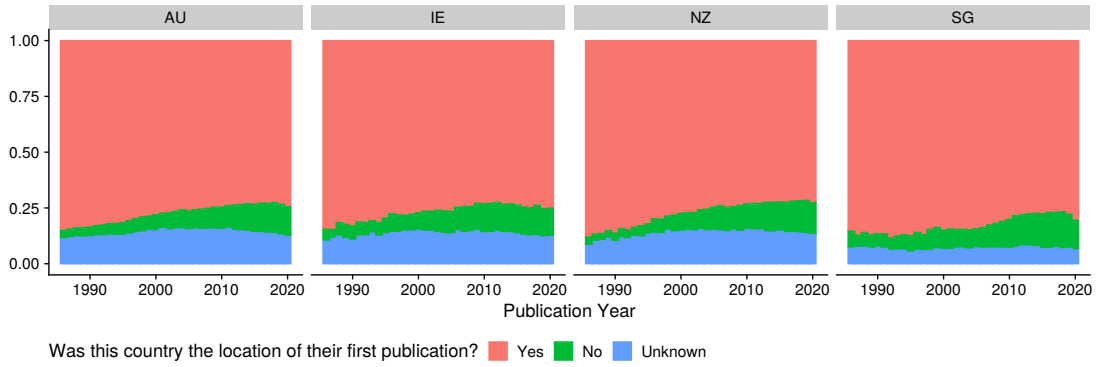

Figure 7: Country of first publication of actively-publishing researchers as per affiliation at the time of their first publication (Source: OpenAlex). Countries were Australia (AU), Ireland (IE), New Zealand (NZ), and Singapore (SG).

in social sciences and humanities (827 researchers per million people) than Ireland or Singapore, but authors in these research fields were fewer than in Australia (958 researchers per million people). Similarly, New Zealand had a higher intensity of researchers actively publishing in life sciences (500 researchers per million people) than Ireland or Singapore, but there were fewer authors in this research field compared with Australia (561 researchers per million people).

The academic age (measured as time since an author's first publication) of researchers increased for all the countries included in this comparison (Figure 6). In 2019, New Zealand had the most experienced workforce with 35.8% of actively-publishing researchers with an academic age of 10 years or more. In contrast, Singapore had an academically younger workforce with only 19.8% of actively-publishing researchers with at least 10 years experience.

Between 1990 and 2019, all four countries had a decrease in the proportion of researchers whose first publication was in that country (Figure 7). In 2019, New Zealand had the lowest proportion (71.6%) of researchers whose first publication was in the same country, and Singapore had the highest proportion (77.8%).

3.3 Entrants to New Zealand's research workforce

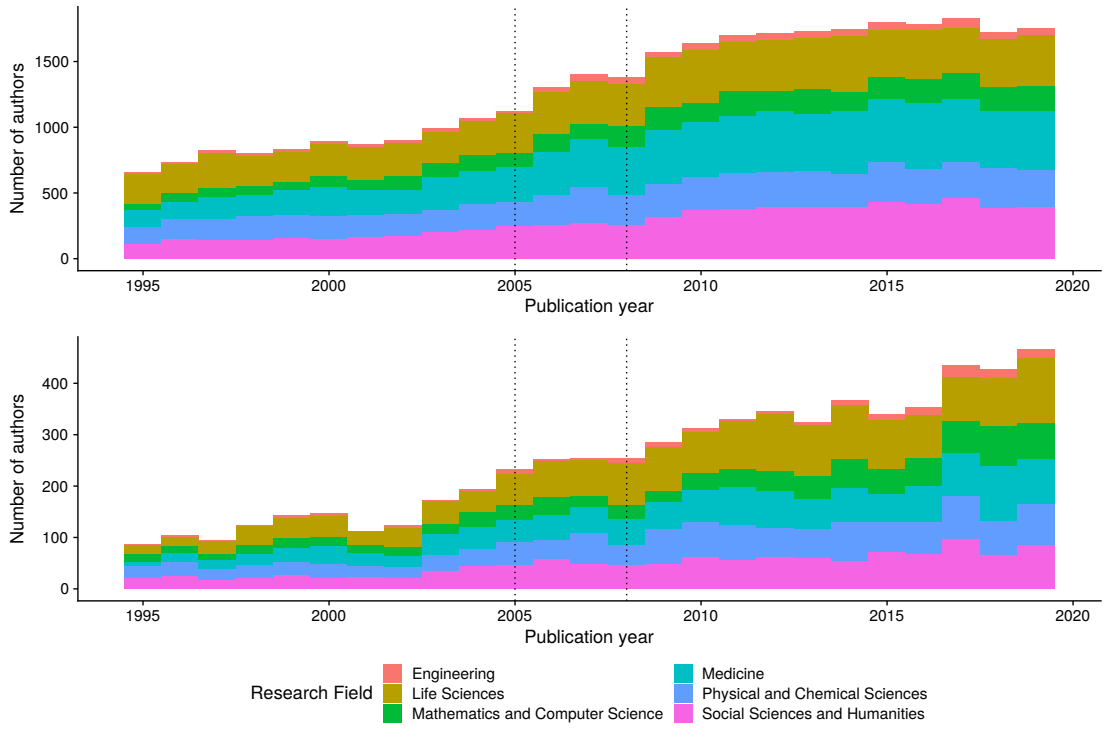

Figure 8: Number of first-time authors, whose first publication was affiliated with New Zealand (top) or elsewhere (bottom), by main research field (Source: OpenAlex). Dotted vertical line at 2005 indicates the year when fees for international PhD students became the same as for domestic students; dotted vertical line at 2008 indicates the first cohort of PhD graduates after the reduction in fees. Yearly accounts adjusted for missing affiliations. Transient authors, who only publish one paper, are not included.

The number of new entrants to the New Zealand research workforce increased over time (Figure 8). There were increases in both the number of first-time authors from New Zealand, and in the number of international-origin authors who published in New Zealand for the first time. For authors whose first publication was affiliated with a New Zealand institution, the annual increases were greatest in the period after 2005, when international student fees became the same as domestic fees. Since 2010, the annual number of new authors whose first publication was affiliated with a New Zealand institution has plateaued. The number of international-origin authors who published in New Zealand for the first time continued to increase between 2010 and 2020. This increase represented a shift in the recruitment of new active publishers towards researchers who were first affiliated with institutions outside of New Zealand.

3.4 PhD graduates

The total number of PhD graduates increased from 618 graduates in 2004 to 1488 graduates in 2019, an annual increase of 6.0% (Figure 9, see also Appendix A, Table A-2). Across the main research fields, the largest increases in the number of PhD graduates over this period were in natural and physical sciences (from 180 to 384 PhD graduates) and in engineering and related technologies (from 48 to 219 PhD graduates).

The increase in PhD graduates in New Zealand since 2004 was largely related to increases in the number of PhD graduates who originated from other countries (Figure 10). In 2004, there were 537 domestic PhD graduates (86.9% of the total); in 2010, there were 771 domestic PhD graduates (76.0% of the total); and in 2019, there were 783 domestic PhD graduates (52.6%). There was a marked growth in the number of international students following the reduction in fees in 2005, with the number of domestic PhD graduates plateauing between 2010 and 2019.

The increases in the number of PhD graduates since 2004, and the increasing proportion of international student graduates, were evident across many of the research fields. In 2019, agriculture, environmental and related studies had the lowest percentage of domestic PhD graduates (18.2%), followed by management and commerce (38.2%), and engineering and related technologies (42.5%). In natural and physical sciences, the total number of domestic PhD graduates decreased between 2010 and 2019 (from 201 to 177 graduates), whereas the total number of graduates increased from 294 to 384 graduates. In 2019, the proportion of domestic PhD graduates was highest in health (68.7%), creative arts (66.7%), and society and culture (63.5%) research areas.

There was little change in the proportion of female PhD graduates over time in most fields (Figure 11; see details in Appendix A, Table A-2). Overall, there were approximately equal numbers of male and female graduates: 48.5% of PhD graduates were female in 2004, and 50.6% were female in 2019. This ratio varied by field, however; creative arts, health, society and culture, and education all had more than 60% female PhD graduates. In contrast, engineering and related technologies had 28.7% female graduates, and information technology had 33.3% female graduates. Research fields dominated by male PhD graduates also had a high number of international students, compared with female-dominated fields that tended to have more domestic students.

The proportion of Māori or Pasifika PhD graduates was consistently small throughout the study period. In 2019, 3.8% of PhD graduates were Māori and 1.6% of PhD graduates

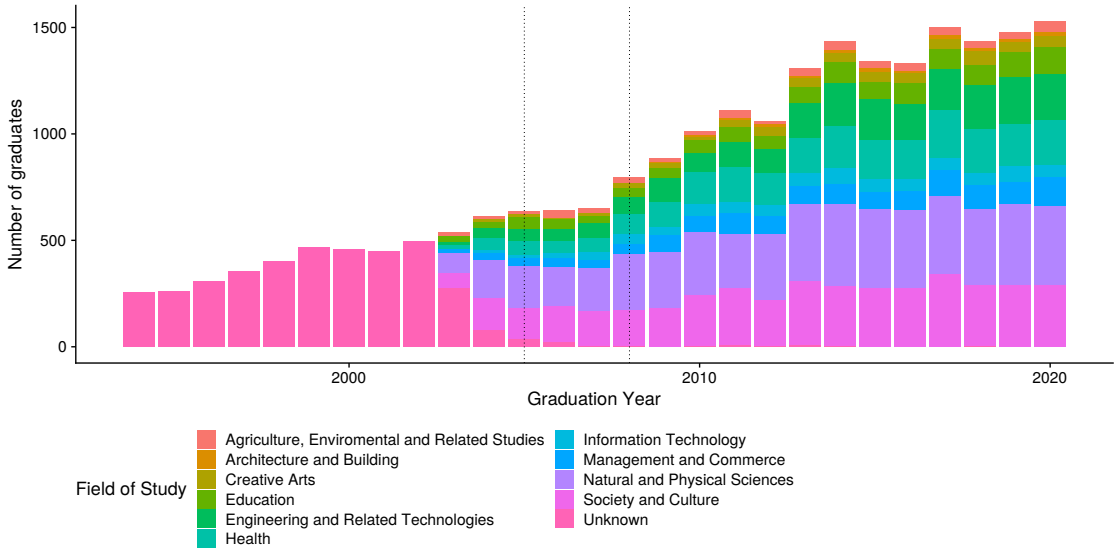

Figure 9: Number of New Zealand PhD graduates over time, by main research field. Dotted vertical line at 2005 indicates the year when fees for international PhD students became the same as for domestic students; dotted vertical line at 2008 indicates the first cohort of PhD graduates after the reduction in international fees (Source: Stats NZ, Integrated Data Infrastructure).

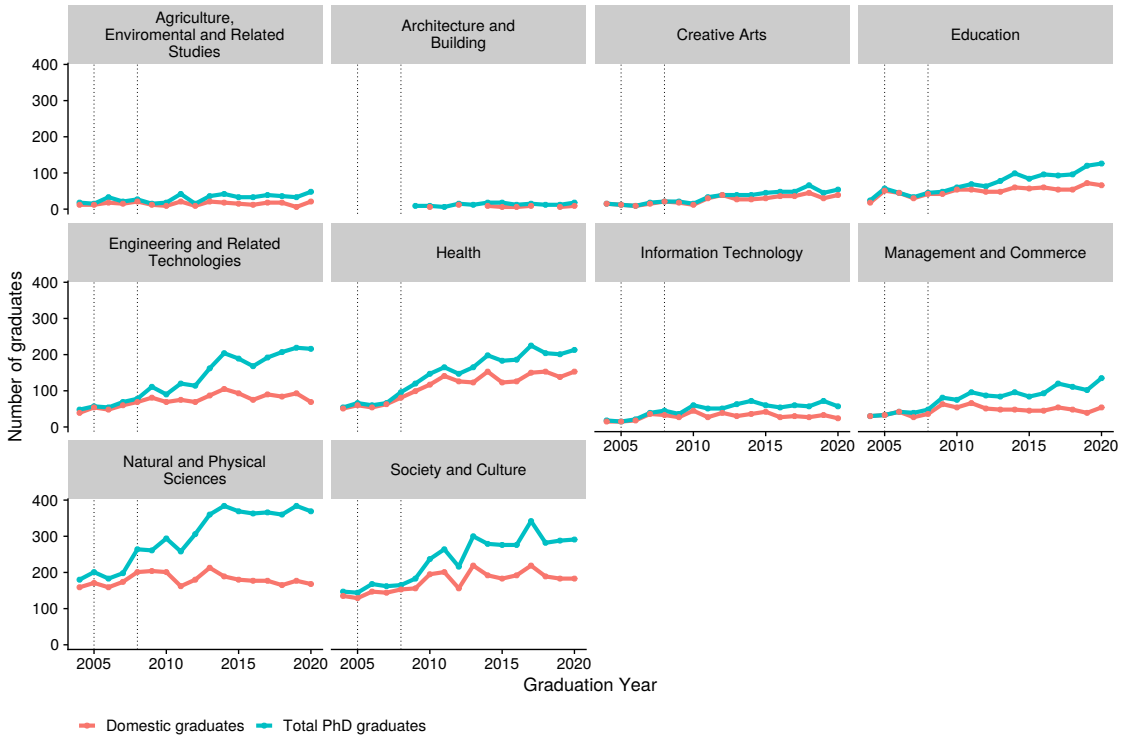

Figure 10: Number of PhD graduates in New Zealand over time by research field. Total number of PhD graduates (blue line) and number of domestic students (red line). Dotted vertical line at 2005 indicates the year when fees for international PhD students became the same as for domestic students; dotted vertical line at 2008 indicates the first cohort of PhD graduates after the reduction in international fees. (Source: Stats NZ, Integrated Data Infrastructure).

Figure 11: Proportion of New Zealand PhD graduates by demographic group and main research field. Dotted vertical line at 2005 indicates the year when fees for international PhD students became the same as for domestic students; dotted vertical line at 2008 indicates the first cohort of PhD graduates after the reduction in international fees. Missing data points indicate that the count was less than six and was suppressed to meet Stats NZ confidentiality rules; the dashed line shows the proportion equal to six graduates (Source: Stats NZ, Integrated Data Infrastructure).

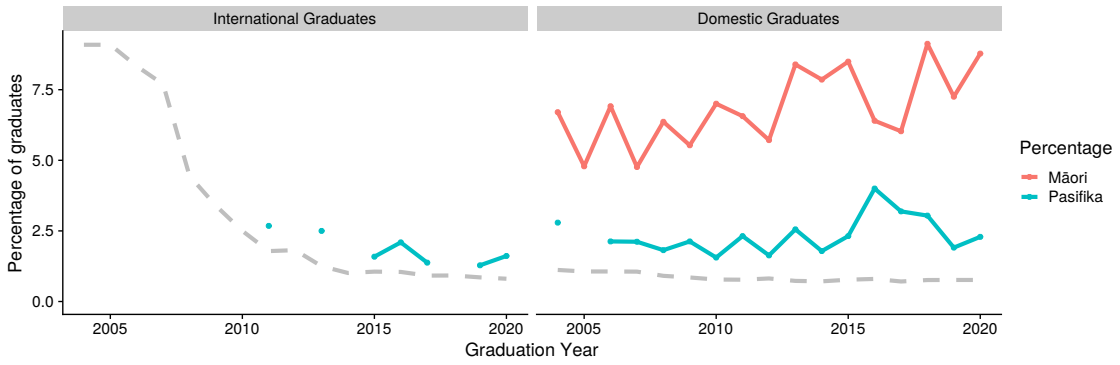

Figure 12: Proportion of PhD graduates of Māori or Pasifika descent, who were enrolled as either international or domestic students in New Zealand. Missing data points indicate that the count was less than six and was suppressed to meet Stats NZ confidentiality rules; the shaded area shows the possible values of these missing points (Source: Stats NZ, Integrated Data Infrastructure).

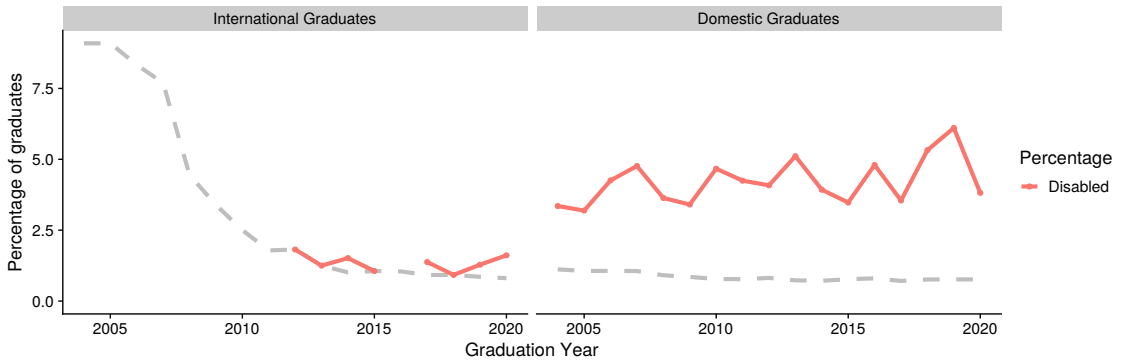

Figure 13: Proportion of PhD graduates who were disabled, who were enrolled as either international or domestic students in New Zealand. Missing data points indicate that the count was less than six and was suppressed to meet Stats NZ confidentiality rules; the shaded area shows the possible values of these missing points (Source: Stats NZ, Integrated Data Infrastructure).

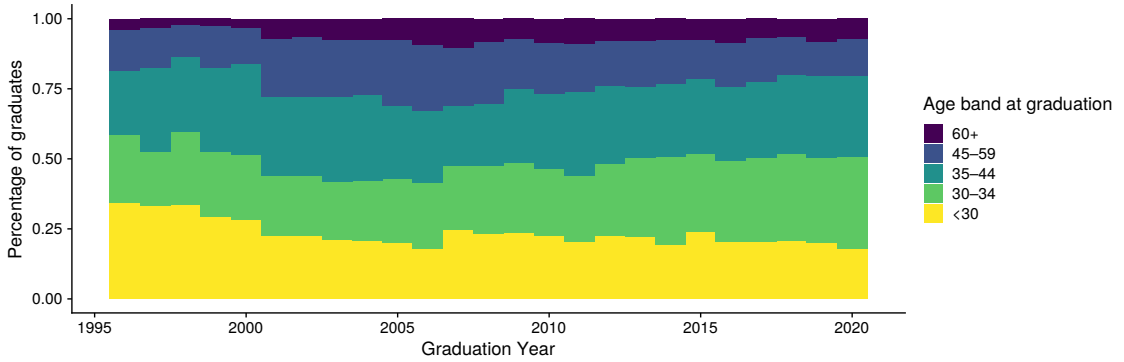

Figure 14: Age of PhD graduates at the time of their graduation (Source: Stats NZ, Integrated Data Infrastructure).

were Pasifika. In comparison, in 2018, around 18% of the New Zealand population were Māori and 8% were Pasifika[4]. The overall proportion of PhD graduates who are Māori or Pasifika has decreased over time (from 5.8% and 2.4% of graduates in 2004, respectively). There were few Māori or Pasifika international students. Restricting the analysis to domestic students, 6.7% of domestic PhD graduates were Māori in 2004, compared with 7.3% who were Māori in 2019 (Figure 12). There was some evidence that the proportion of domestic PhD graduates who were Māori increased over the period 2004 to 2020, with a simple linear regression indicating an annual increase with a mean of 0.16% (with a standard error of 0.05%). In 2004, 2.8% of domestic PhD graduates were Pasifika, compared with 1.9% in 2019. There was no evidence from these data of either an increase or a decrease in the proportion of domestic PhD graduates who were Pasifika over the period 2004 to 2020.

For most research fields, there were only up to five Māori or Pasifika PhD graduates in a single year. There were few Māori or Pasifika PhD graduates in engineering and related technologies. Across research fields, in 2019, the highest proportions of Māori PhD graduates were in education (7.5%) and in society and culture (6.3%).

In 2019, 6.1% of domestic PhD graduates were disabled. There was a smaller proportion of international students who were disabled (1.9% in 2019). There was no evidence of either an increase of a decrease in the number of domestic PhD graduates who were disabled (Figure 13).

There has been a decrease in the proportion of graduates who are younger than 30 years (Figure 14); in 2019, around 50% of graduates were at least 35 years old. This finding indicates that many PhD graduates did not follow an uninterrupted career path from secondary education to tertiary and postgraduate study.

The majority of international PhD graduates did not remain in New Zealand after five years of their graduation (Figure 15; although some of these researcher may have returned subsequently). Comparing PhD graduates with graduates who have a Bachelor's degree as their final qualification, PhD graduates were less likely to remain in New Zealand following graduation. International PhD students are currently able to stay in New Zealand on a post-study work visa for up to three years; if they find skilled

[4]https://www.stats.govt.nz/information-releases/national-ethnic-population-projections-2018base2043-update/

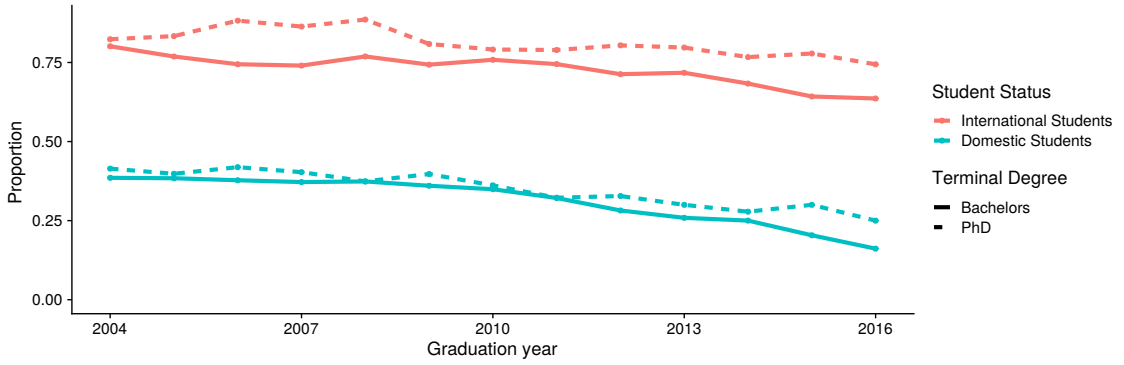

Figure 15: Proportion of PhD graduates who have left New Zealand five years after their graduation (Source: Stats NZ, Integrated Data Infrastructure).

employment during this time, they may become eligible for a skilled migrant visa. Between the graduation years of 2004 and 2016, there was a decrease in the proportion of both domestic and international students who leave New Zealand within five years of graduating.

3.5 Employment and precarity

The present assessment of the New Zealand research workforce also included an analysis of academic precarity. This analysis used publication records to assess the period of time an academic researcher was actively publishing. Researchers who only published a single paper were considered transient and not included in the assessment.

The probability of researchers leaving academic publishing showed a U-shaped trend (Figure 16). This trend means that researchers were more likely to leave in early years of an academic career and in later years, but less likely to leave in mid-career years. The probability of a researcher leaving academic publishing was around 10% in the year after their first publication. For earlier cohorts, the probability of leaving academic publishing decreased to around 5% for mid-career researchers. The most recent 2016 cohort did not show a clear decrease in the probability of leaving academic publishing over the first five years. All cohorts showed an increase in the probability of leaving academic publishing in recent years, irrespective of the career change. The size of the cohorts increased with time; however, there were steep declines in the number of each cohort remaining in academic publishing (Figure 17).

The mark-recapture analysis allowed a formal statistical assessment of yearly attrition rates across different cohorts (Figure 18). There was no clear trend in the attrition rates from this analysis. There was an increase in attrition for the most recent cohorts in years two, five, six, and seven. Nevertheless, the associated uncertainties were large. In

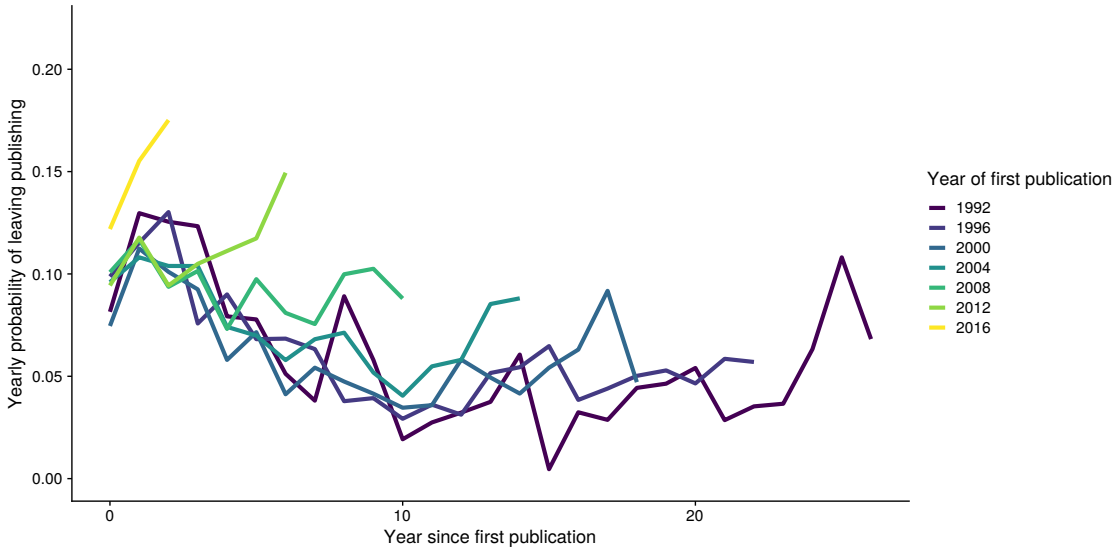

Figure 16: Yearly probability of an individual member of a cohort leaving publishing, by time following their first publication (Source: OpenAlex). A seperate line is shown for each cohort. Cohorts were defined as all researchers with their first publication in the same year.

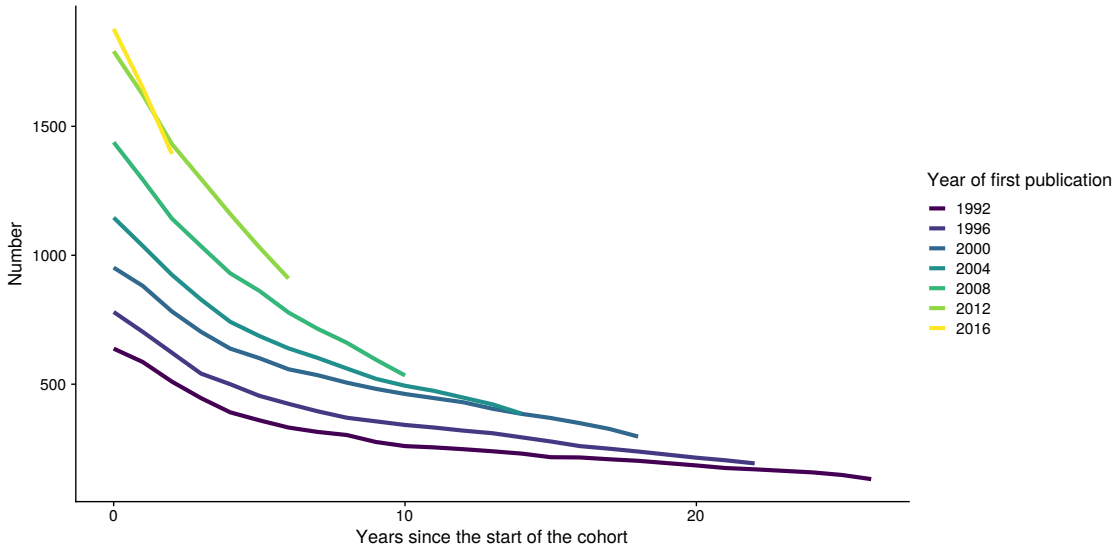

Figure 17: Number of New Zealand researchers who published academic papers, since the year of their first publication with a New Zealand affiliation (Source: OpenAlex). Cohorts were defined as all researchers with their first publication in the same year.

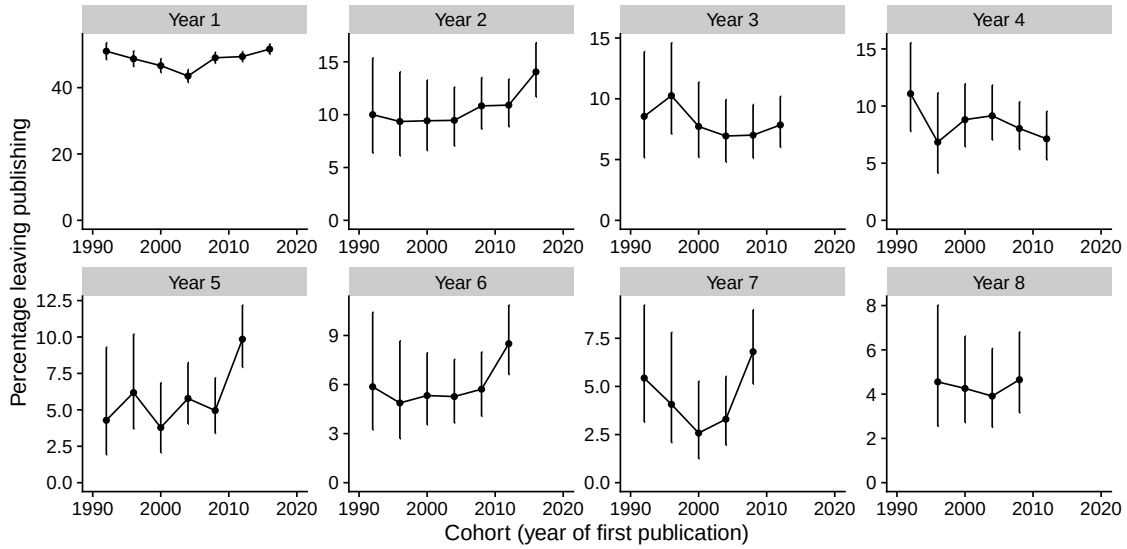

Figure 18: Estimated annual percentage (mean and 95% confidence intervals) of New Zealand researchers leaving publishing (Φ, see Methods). The estimated percentage is shown for each academic age (years since first publication) by entry year of the cohort. Cohorts were defined as all researchers with their first publication in the same year. In each plot, the x-axis is the entry year of the cohort, and the y-axis is the percentage of academic publishers leaving publishing. Each plot is labelled by the academic age of the researchers, for example, the plot labelled '1' shows how the attrition of researchers after their first year.

addition, it is possible that the latest years of each cohort were impacted by the truncation of the data. Because authors do not publish in every year, it is unclear whether a lack of publishing in recent years means that an author was no longer actively publishing, or if they will continue to publish in the future.

3.6 Tertiary funding and employment

The tertiary sector generated the largest proportion of New Zealand's research output, and provided employment for a considerable number of graduates. The number of enrolled PhD students per full-time equivalent (FTE) staff at New Zealand universities increased considerably in the last 20 years, reaching 1.74 PhD students per academic FTE (at a level of lecturer/tutor or above) in 2019 (Figure 19). In 2020, this number fell slightly to 1.67 enrolled PhD students per academic FTE, although it was over twice the number of PhD students per academic FTE enrolled in 2003 (0.72), when the PBRF was first introduced. At the same time, the number of academic FTE staff remained constant over this period (there were 5945 academic FTE staff in 2020, compared with 5875 and 5915 FTE staff in 2008 and 2003, respectively).

The PBRF provides substantial funding for tertiary institutions, contributing NZ $315 million in 2020 (Figure 19). The majority (over 96%) of this funding was for universities (Ministry of Education 2022). Other government funding for tertiary institutions has included research funding top ups before the introduction of the PBRF, and funding for Centres of Research Excellence (CoREs). Total government funding to tertiary institutions increased markedly over time, even when excluding funding associated with student fees or contestable funding such as the Marsden or Endeavour funds.[5] The overall funding increase was reflected in the research funding per FTE staff at these institutions. While the total funding increased following the introduction of the PBRF, it has remained relatively static since 2008: after inflation adjustment, total funding was NZ $194 million in 2003, it increased to NZ $354 million by 2008, and was NZ $371 million in 2019. The static funding was reflected in the static number of academic FTEs at universities, so that research funding per enrolled research student decreased from NZ $52,874.00 per enrolled student in 2008 to NZ $37,303.00 per enrolled student in 2020.

Staffing levels at New Zealand universities changed over time, dependent on the role of staff (Figure 20). Since 2016, when the data collection method changed, the number of FTE staff at lecturer and tutor levels decreased, whereas the number of FTE staff in all other roles showed some increases. Increases in FTE staff at the level of professor or dean indicated that established academic staff continued to receive promotions, whereas the overall decrease in FTE lecturers appeared to indicate fewer openings for less experienced staff.

There was also an increase in research-only staff and in research support staff. Increases in research-only staff during this time may be related to staffing increases through short-term postdoctoral employment linked to research grants that require additional research capacity for a set period of time.

Between 2012 and 2019, there was some increase in the number of academic staff

[5] In 2020, the Marsden and Endeavour funds were worth NZ $79m and $228m, respectively; see: https://www.mbie.govt.nz/assets/endeavour-fund-investment-plan-2022-2024.pdf.

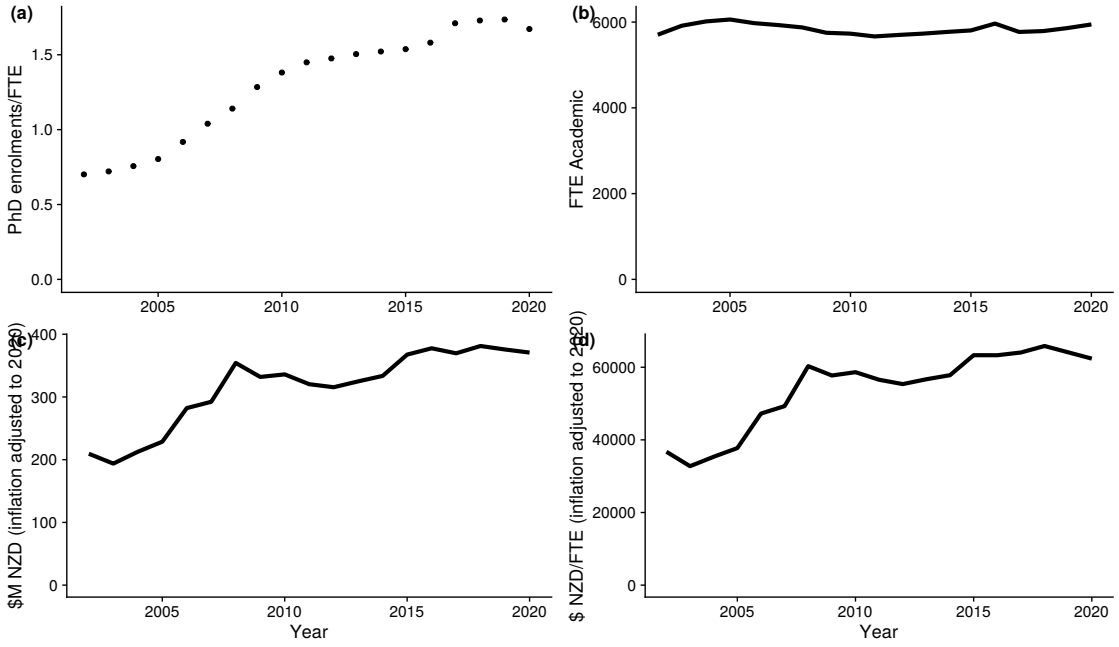

Figure 19: Funding and employment at New Zealand tertiary institutions (Source: Education Counts, Ministry of Education 2022.). a: Number of PhD enrolments at universities divided by full-time equivalent (FTE) academic staff members ranked at lecturer/tutor or above. b: Number of FTE academic staff members at universities. c: Direct government research funding to the tertiary sector, in million NZD, inflation-adjusted to 2020. d: Research funding per academic FTE (inflation-adjusted).

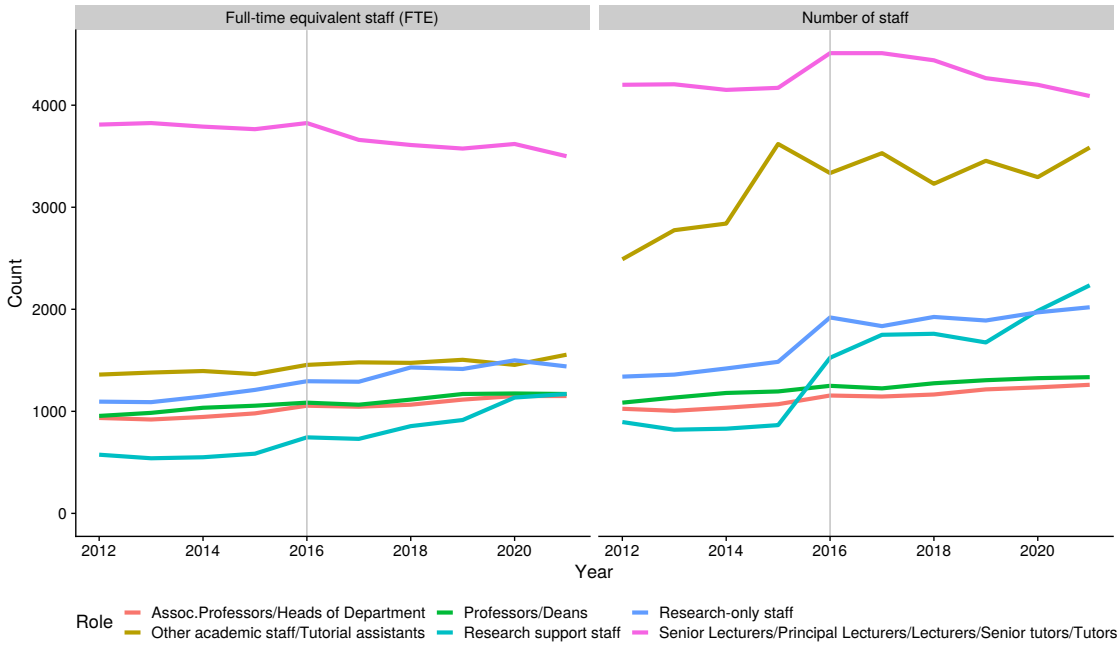

Figure 20: Number of academic and research staff at New Zealand universities over time (Source: Ministry of Education 2022). Vertical grey line at 2016 indicates the year when the data collection methods changed: prior to this year, counts were collected for a single week in August, whereas after 2016, counts were collected for the entire year.

at universities, from 8,800 academic staff in 2012 to 10,270 academic staff in 2019 (Ministry of Education 2022). Over this period, the number of full-time academic staff at universities decreased (from 5,735 to 5,505 staff) whereas the number of part-time staff increased (from 3,065 to 4,745 staff). Similarly, there was some increase in the number of university research staff (from 1,220 research staff in 2012 to 1,400 research staff in 2019), but there was a considerable increase in the number of recorded part-time research staff (from 1,015 to 2,780 staff over the same period). Nevertheless, because the data collection method changed in 2016, from data being collected at a particular point in time to being collected throughout the year, this change would have led to an increase in the number of part-time temporary staff.

3.7 International movement of researchers

Researchers starting their career (i.e., publishing their first academic paper) in New Zealand may subsequently have left academic publishing or continued their career in other countries (Figure 21). Over time, there was a decrease in the proportion of active researchers remaining in New Zealand since their first publication. This decrease was evident across all cohorts, but particularly pronounced in recent cohorts.

For New Zealand researchers who remained active in academic publishing, publication records included authors who continued to publish from overseas, and authors who published overseas in the interim before publishing from New Zealand again (returnees) (Figure 22). For each author cohort, the most notable increase in publication records from overseas was in the initial period following the first New Zealand publication. There was a delay between this increase and researchers returning to New Zealand. For the majority of New Zealand's active research workforce, there were no publication records with affiliations overseas; i.e., most researchers active in the New Zealand

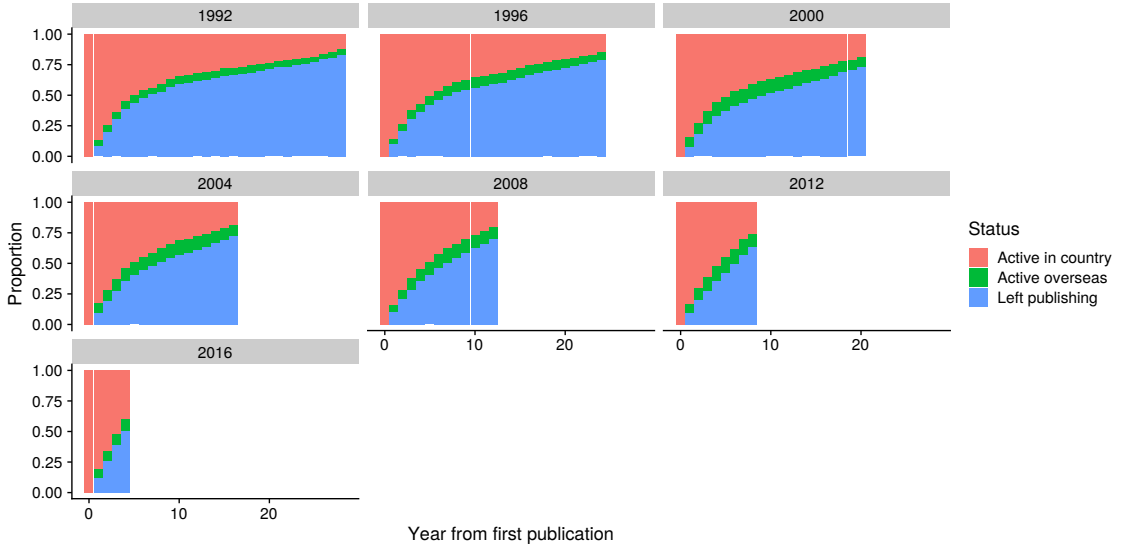

Figure 21: Proportion of New Zealand authors over time following the year of their first publication, by status (Source: OpenAlex). Data are shown for each cohort, defined as all researchers with their first publication in the same year. Status was defined as: left publishing; active overseas, publishing with an overseas affiliation; in country: publishing with a New Zealand affiliation.

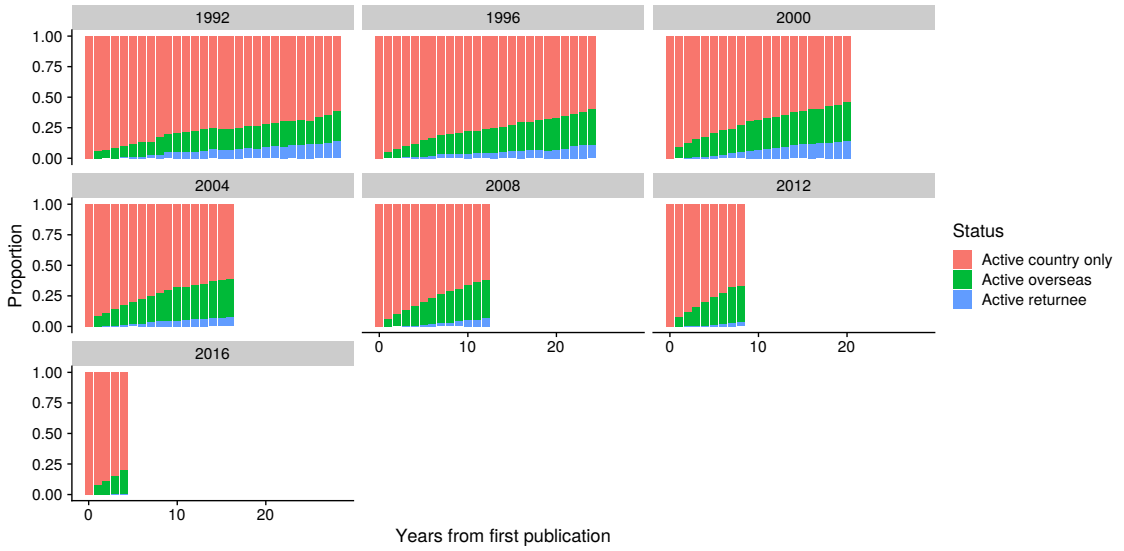

Figure 22: Proportion of active New Zealand authors by status over time following the year of their first publication (Source: OpenAlex). Data are shown for each cohort, defined as all researchers with their first publication in the same year. Status was defined as: active country only, publications with only New Zealand affiliations; active returnee, publications with overseas affiliations followed by New Zealand affiliations; active overseas; publications with only overseas affiliations.

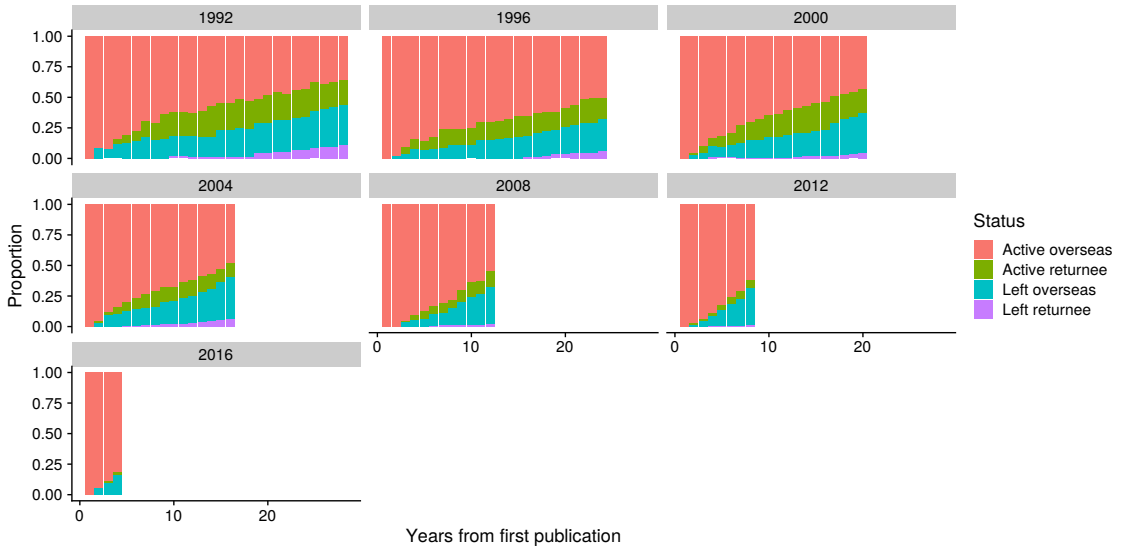

Figure 23: Proportion of authors with their first publication from New Zealand and with subsequent publications from overseas, by status (Source: OpenAlex). Data are shown for each cohort, defined as all researchers with their first publication in the same year. Status was defined as: left overseas, leaving academic publishing while overseas; left returnee, leaving academic publishing after returning to New Zealand; active returnee, publishing actively after returning from overseas; active overseas, publishing actively from overseas.

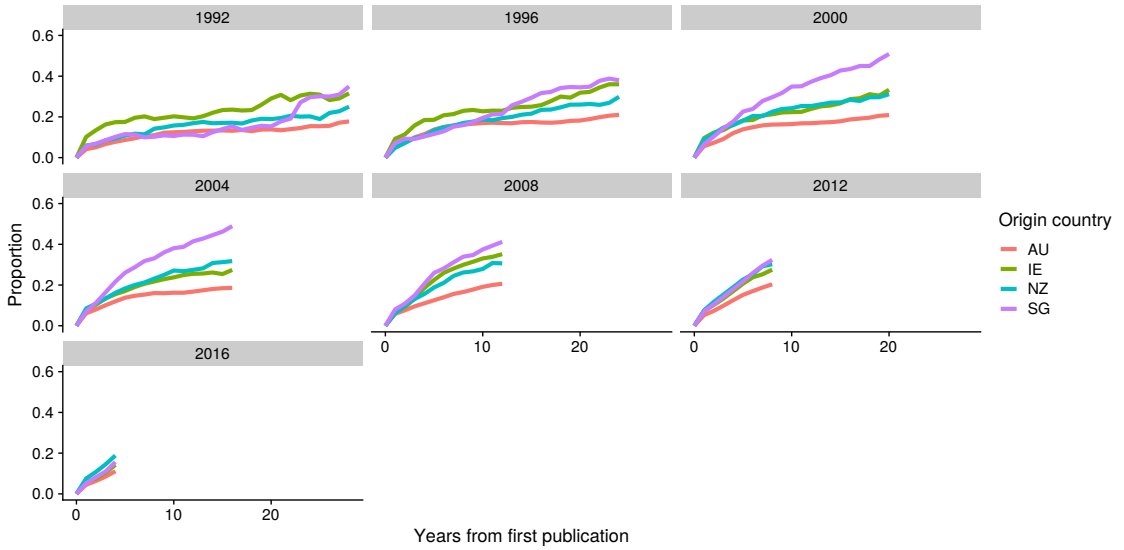

Figure 24: Proportion of active authors who continued to publish in their country of origin over time, by cohort and country of origin. Cohorts were defined as all researchers with their first publication in the same year. Countries were Australia (AU), Ireland (IE), New Zealand (NZ), and Singapore (SG) (Source: OpenAlex).

research workforce published with New Zealand affiliations only.

For New Zealand researchers who published with overseas affiliations, the proportion of authors leaving academic publishing was smaller than the proportion for all New Zealand authors (Figure 23). Nevertheless, a small proportion of this author group returned to publishing from New Zealand.

An international comparison of researchers showed that the proportion of active authors who continued to publish in their country of origin was similar in New Zealand and Ireland (Figure 24). Their proportion was notably lower for Australian researchers. Across cohorts, each subsequent cohort showed an increase in the proportion of researchers working from overseas within a shortening time frame, reflecting an increase in global academic movements.

Reflecting the size of the tertiary sector, the entry of experienced authors (the publishing of a paper five years after the first paper with a known New Zealand affiliation) was mainly associated with tertiary institutions (Figure 25). The decreases in numbers for cohorts after 2012 were likely due to data limitations (such as publications having unknown affiliations, or delays between publications), rather than a decline in recruitment. In all the sectors, around 80% of the experienced authors had their first publication in New Zealand. Universities tended to recruit more staff who first published overseas, and healthcare research institutes tended to recruit more staff who first published in New Zealand. Averaging over the 2010 to 2015 cohorts, the percentage of experienced staff with their first publication in New Zealand was 72.5% (tertiary institutions), 80.2% (other), 82.2% (CRI), 86.5% (healthcare).

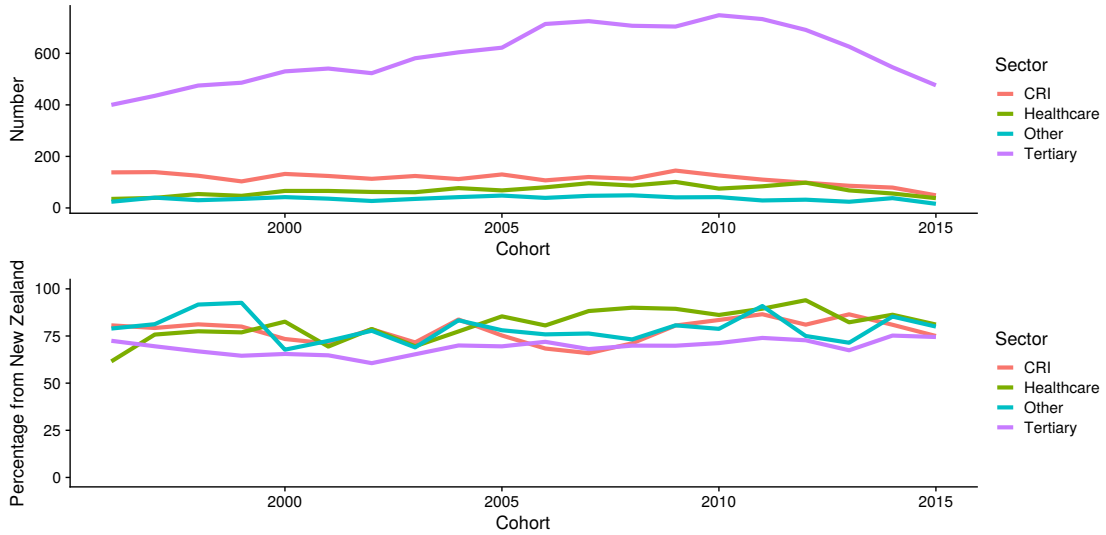

Figure 25: Experienced authors first affiliation after 5 years (Source: OpenAlex), by cohort (year of first publication). Top: Number of experienced authors by research sector. Bottom: Percentage of experienced authors with their first publication from a New Zealand affiliation. CRI, crown research institute.

3.8 Arrival and retention of international researchers

There were similar trends in the number of international researchers joining the research workforce in New Zealand compared with other countries (Figure 26). The majority of international researchers arrived near the start of their career, and this timing was particularly pronounced in Singapore and also Ireland.

Trends across countries were also similar for international-origin researchers leaving the country's workforce (Figure 27). Most of these researchers who left, left after spending between one to eight years in a country's research workforce. These researchers may have stayed in the country either as active or inactive researchers.

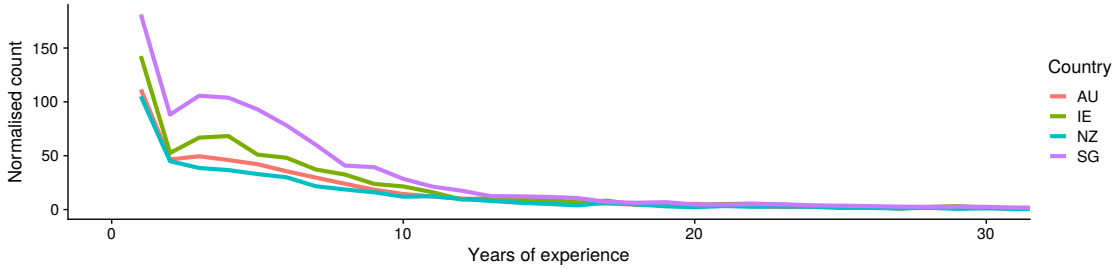

Figure 26: Number of international researchers entering another country's research workforce since 2000, by their years of experience (Source: OpenAlex). Data were normalised by each country's 2015 population size. Countries were Australia (AU), Ireland (IE), New Zealand (NZ), Singapore (SG).

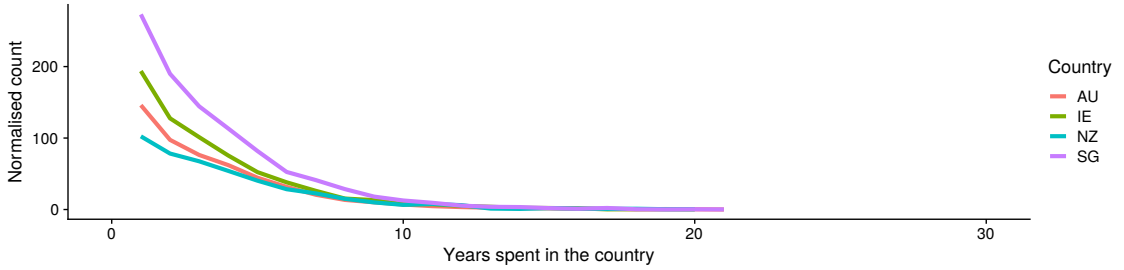

Figure 27: Number of international-origin researchers leaving a country's research workforce by number of years spent in this workforce (since 2000) (Source: OpenAlex). Data were normalised by each country's 2015 population size. Countries were Australia (AU), Ireland (IE), New Zealand (NZ), Singapore (SG).

4. DISCUSSION

Academic publishing data provide some insight into the research workforce. Most actively-publishing researchers from New Zealand were affiliated with tertiary institutions, with a smaller number affiliated with healthcare institutions and CRIs. There were also researchers affiliated with a range of other institutions, from independent research organisations to private companies. Overall, in 2019, there were approximately 18,029 actively-publishing researchers in New Zealand. Overall, the number of actively-publishing authors grew at an annual rate of 4.3% between 2010 and 2019. The CRI sector appeared to have stagnated, however, with a growth of only 0.9% per annum in the number of actively-publishing researchers over the same period. Over time, the share of CRIs of New Zealand's academic workforce has decreased: in 2019, only 8.0% of actively-publishing researchers were affiliated with CRIs.

The increase in the number of actively-publishing researchers at universities was not reflected in FTE numbers, or in research funding, which both stayed constant over this period. This aspect may have been a combination of an increase in the number of PhD students and in the number of part-time staff (so there are more individual staff per FTE). The PBRF system incentivises university staff to increase their academic research publications, so there may also have been an increase in the participation of university academic and research staff in publishing.

When comparing the number of actively-publishing researchers per million people (researcher intensity) between countries, data showed that New Zealand fell behind the comparison countries included here (Australia, Ireland, and Singapore). Although New Zealand and Singapore had a similar researcher intensity in 2000, by 2019 New Zealand had less than half the researcher intensity than that of Singapore; New Zealand also had the lowest researcher intensity of any of the comparison countries. Growth in researcher intensity in New Zealand has slowed since 2010, whereas the number of actively-publishing researchers per million people in the comparison countries increased between 2010 and 2019. The relatively slow growth in researcher intensity in New Zealand may be linked to the static number of researchers at CRIs, and to inflation-adjusted research funding to universities remaining relatively unchanged.

The introduction of the PBRF in 2003, and equal access to PhD studies for international students in 2005 led to more than double the number of annual PhD completions. The increase was associated with an increase in the number of international students. These

international students did not typically stay in the New Zealand research workforce; around 80% of researchers who stayed in publishing left New Zealand within five years. New Zealand is supporting the education of international PhD students, who contribute to the research system while they are in the country, but who typically leave subsequently. This study did not use the publication data to examine collaborations between researchers at different institutions. The publication records could be used in this way, to help understand whether collaborations with New Zealand researchers were retained by these PhD graduates after they left the country.

Although the current analysis of publication records provides information about New Zealand's research workforce, this approach was limited to researchers who actively publish academic papers. These publication data fail to capture information of active researchers who make up a proportion of the research workforce but do not disseminate their research findings through academic publications, such as researchers who conduct commercially-sensitive studies.

The present study prevented an investigation of collaboration patterns within New Zealand and of potential changes resulting from changes in government policy. This type of analysis could be pursued with the OpenAlex data and New Zealand data subsets identified here. Similarly, further potential analyses based on these data include a focus on precarity and career progression by research field and by research organisations. The publication data has its limitations, in particular: there may be substantial delays between active research and its eventual publication; there are changes in the accuracy of the data which likely affects the analysis in unknown ways; and there is no demographic information associated with the dataset. Despite these limitations, the publication data are a rich source of information, which is openly available. This study is a broad overview of the dataset, providing the basis for more detailed analyses in the future.

5. ACKNOWLEDGMENTS

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APPENDIX A SUPPLEMENTARY INFORMATION

A.1 Authorship counts and missing affiliations

The present data analysis addressed authorship counts and missing affiliations through the approach detailed below.

For a count of authors identified with an organisations affiliation in a year n, the number of authors was approximated as:

$$n_{total} = n/p_{found}, \tag{A-1}$$

where p_{found} is the probability that a particular author was identified.

The probability that a particular author was not identified with at least one affiliation that year $p_{!found}$ was approximately

$$p^{j}_{\text{affiliation missing}}, \tag{A-2}$$

where j is the number of papers authored by this author in that year. Therefore, the probability that an author was missed was:

$$p_{!found} = 1 - p^{j}_{\text{affiliation missing}}, \tag{A-3}$$

which was then used to approximate

$$p_{found} \approx 1 - p^{\hat{j}}_{\text{affiliation missing}}, \tag{A-4}$$

where $\hat{j}$ is the mean number of publications per author in that year.

Table A-1: Number of authors publishing with New Zealand affiliations by research field and year, for the period between 1990 and 2022.

Publication year	Social Sciences and Humanities	Life Sciences	Physical and Chemical Sciences	Mathematics and Computer Science	Engineering	Medicine	Unknown
1990	370	832	995	220	6	777	180
1991	409	753	1033	195	9	752	211
1992	452	976	1049	230	14	843	232
1993	524	970	1029	303	17	849	184
1994	591	1005	1137	294	15	934	212
1995	592	1213	1132	363	9	921	238
1996	725	1154	1262	410	21	906	262
1997	794	1310	1352	431	15	1037	312
1998	817	1289	1448	461	9	1204	321
1999	934	1285	1536	458	15	1286	357
2000	959	1433	1488	532	23	1383	384
2001	1016	1416	1453	588	25	1301	346
2002	1028	1467	1539	699	23	1347	403
2003	1233	1350	1523	684	25	1535	429
2004	1306	1369	1721	792	15	1731	465
2005	1491	1577	1702	892	11	1992	496
2006	1682	1739	1915	899	20	2081	476
2007	1934	1875	2258	984	29	2556	434
2008	2163	1908	2048	1165	35	2728	533
2009	2207	2103	2147	1266	21	2968	479
2010	2456	2073	2455	1245	34	3057	627
2011	2774	2146	2546	1427	39	3239	647
2012	2846	2306	2603	1293	46	3843	665
2013	2908	2345	2618	1535	46	3942	700
2014	3059	2194	2694	1514	39	4290	781
2015	3344	2388	2651	1562	29	4527	751
2016	3618	2336	2814	1583	41	4493	812
2017	4041	2511	2858	1742	47	4805	781
2018	3889	2412	2778	1847	51	4766	845
2019	4014	2423	2938	2062	51	5026	905
2020	4340	2541	3047	1951	57	5527	1004
2021	5501	3006	3571	2652	70	6813	1960
2022	2664	1850	2091	1111	68	3320	996

Table A-2: Demography of New Zealand PhD graduates between 2003 and 2020. Disability status was included when it was reported to the education provider by a student.

Graduation year	Total	Female	Disabled	Māori	Pasifika	International
2003	546	243	21	33	6	87
2004	618	300	21	36	15	81
2005	642	312	18	27	6	78
2006	639	318	24	39	15	75
2007	651	300	27	30	15	84
2008	804	402	24	42	15	144
2009	885	459	24	42	18	180
2010	1014	537	39	54	15	243
2011	1119	555	36	51	27	339
2012	1068	540	36	45	15	333
2013	1308	651	48	72	33	486
2014	1440	732	42	66	18	600
2015	1347	690	33	66	27	573
2016	1323	693	39	48	39	573
2017	1503	765	42	51	33	654
2018	1440	723	48	72	30	651
2019	1488	753	54	57	24	705
2020	1530	795	39	72	33	744