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Abstract

The introduction of performance-based research funding systems (PBRFS) in many countries has generated new information on the impact of these systems. Recent research has considered whether such systems generate convergence or divergence of research quality across universities and disciplines. However, little attention has been given to the processes determining research quality changes. This paper utilises anonymised longitudinal researcher data over fifteen years of the New Zealand PBRFS to evaluate whether research quality changes are characterised by convergence or divergence, and the processes determining those dynamics. A unique feature of this research is the use of longitudinal data to decompose changes in researcher quality into contributions arising from the entry, exit and quality transformations of retained researchers, and their impacts on the convergence or divergence of research quality of universities and disciplines. The paper also identifies how researcher dynamics vary systematically between universities and disciplines, providing new insights into the effects of these systems.

Keywords: Education policy, performance-based research funding systems, research quality, convergence, universities.

JEL classifications: I2; I23; I28; L38.

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1. Introduction

Performance-based research funding systems (PBRFS) are designed to improve research output, quality and impact, and to strengthen the accountability of universities for the use of public funds. They involve a range of incentives, created in particular by the metrics used to measure research quality, which are designed to encourage institutional and individual changes, although unintended consequences can also result.[1] In evaluating performance outcomes of a PBRFS, it is important to know if the design features led to the initially stronger universities capturing an increasing share of research funds, or to a catch-up process whereby initially weaker universities raised their standards at a faster rate. This relates to what is referred to as beta-convergence, defined as a systematic tendency for lower-quality universities to experience relatively higher growth rates compared with higher-quality universities. A further type of convergence, called sigma-convergence, refers to the overall dispersion of university research quality.[2]

Despite the large literature on PBRFSs, very few systematic attempts have been made formally to assess their convergence properties. However, Buckle *et al*. (2020) used information about the first two full rounds, in 2003 and 2012, of the New Zealand (NZ) PBRFS.[3] They found significant evidence for both beta- and sigma-convergence. Subsequently, Checchi *et al*. (2020) adopted the same technique to examine Italian universities, following the introduction of the Italian PBRFS (VQR). They found convergence of research quality of Italian universities between the VQR rounds of 2004 and 2010, and between 2011 and 2014.

The present paper extends this earlier work in several ways. First, in the NZ context, it makes use of the third full round carried out in 2018. This extension allows investigation of whether changes in research quality during the second period (2012 to 2018) were systematically related to the previous responses from 2003 to 2012. Second, more detailed information is available about researchers in each round, including gender and equivalent full-time (EFT) status, which allows for further control variables to be included in the analysis. The third, and most important extension, is that the precise sources of convergence are examined in detail. These are linked directly to the incentives created by the PBRFS. This is achieved by investigating the nature of

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[1] On the development of PBRFSs see, for example, OECD (2010), Hicks (2012), de Boer (2015), Wilsdon *et al.* (2015) and Kolarz *et al.* (2019). Examples of assessments and critical evaluations of these schemes include Hare (2003), Broadbent (2010), Adams and Gurney (2010), Payne and Roberts (2010), Martin (2011), Woerlert and McKenzie (2018), Buckle and Creedy (2019a, 2020), Checchi *et al.* (2019), Buckle *et al.* (2021).

[2] On the use of these terms in the cross-country growth literature, see Quah (1993). These types of convergence are examined in detail in Buckle *et al*. (2020).

[3] There was an incomplete round in 2006.

the transitions involved in achieving quality improvements. Essentially, quality changes arise from differential entry, exit and quality transformations (of those remaining within the same university) of individual researchers. Previous research has shown that NZ universities have not systematically relied on making changes to the discipline composition within universities.[4]

This paper presents techniques that identify the contributions of exit, entry and quality transformation of researchers to the growth in research quality following the introduction of a PBRFS. Each university is incentivised to manage the process of improvement in research quality, subject to constraints.[5] The nature of the incentives in the PBRFS design is likely to influence relative responses and therefore whether they generate convergence or divergence.[6] The benefits of the turnover of researchers of a particular quality vary by the type of university. In turn, the characteristics of a university's turnover, and quality transformation of incumbents, depend on its initial average research quality. These determine the process of convergence of research quality among all universities within the system.

The New Zealand scheme was designed to unbundle the research component of Government funding of New Zealand tertiary education organisations, and allocate the research component based on research performance rather than the number of students; see New Zealand Tertiary Education Commission (2019, p. 11). Three measures are used to allocate Government funding to support research at universities and other tertiary education organisations. The largest component, the focus of this paper, is Quality Evaluation. This comprised 60 per cent of the funds allocated following the 2003 and 2012 assessments and 55 per cent following the 2018 assessment.[7] The system substantially changed the incentives facing individuals, departments and universities. When the PBRFS was introduced, there was no explicit statement of whether an aim was to generate more concentration of higher-quality research.

The quality metric used by the NZ PBRFS is described in Section 2. Section 3 briefly summarises the main research quality transitions, for all NZ universities combined, that have taken place over the periods 2003 to 2012, and 2012 to 2018. The contributions to a university's measured research quality of exits, entrants and quality transformations of incumbent

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[4] Buckle *et al.* (2021, p. 17) discuss a number of constraints arising from teaching requirements and the NZ funding system, which have limited the scope for universities to change their discipline composition.

[5] On management responses to the introduction of a PBRFS, see Adams (2008) and Woelert and McKenzie (2018).

[6] In the UK context, Barker (2007, p. 6) suggests that the funding weights disproportionately rewarded universities which achieved high quality scores, and therefore led to divergence. However, convergence properties for the UK scheme cannot be tested formally, as in the present paper, because the metrics involve only a small number of qualitative categories, and not all academics needed to be included in evaluations.

[7] The other components are Research Degree Completions (25 per cent of the allocated funds) and External Research Income (15 per cent of the allocated funds following the 2003 and 2012 assessments and 20 per cent following the 2018 assessment).

researchers are set out in Section 4. Section 5 provides initial empirical results regarding beta-convergence and sigma-convergence. Section 6 reports the contributions of exits, entrants and quality transformation of researchers to research quality changes for universities and academic disciplines (subject areas), and Section 7 examines these component effects on convergence. Section 8 concludes.

2. The New Zealand PBRFS: measurement of research quality

The assessment of research quality in the NZ PBRFS is based on the performance of all eligible individual researchers within each university.[8] The assessment method is based on peer review, which considers a range of research outputs over the previous six years. The process has remained the same for all assessment rounds. The individual performance measures for all assessment rounds are maintained by the Tertiary Education Commission (TEC).

Each researcher is assigned to a quality category (QC) by a complex peer-review process undertaken by a panel of experts in each subject area. There are four QCs, indicated by A, B, C and R, where the highest category is A, and R indicates an absence of significant research outputs. These QCs are used to allocate funding to universities, and are used to compute a quantitative performance score, referred to as an Average Quality Score (*AQS*) for each subject area and university, defined as follows.[9] Each individual, h, is given a cardinal score, G_h, depending on the QC: 10 for A; 6 for B; 2 for C; and 0 for R. The average quality score, *AQS*, is the employment-weighted arithmetic mean score.[10]

Define the full-time equivalent (FTE) employment weight of person, h, as $e_h \leq 1$, and let n denote the number of employees. The *AQS* for a university or discipline group is:

$$AQS = \frac{\sum_{h=1}^{n} e_h G_h}{\sum_{h=1}^{n} e_h} \qquad (1)$$

The data used here include the QC assigned to every researcher who participated in any of the assessment rounds, in 2003, 2012 and 2018.[11] It also includes an anonymous identifier, age,

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[8] Those eligible include all research and teaching staff who are employed on the PBRF census date under an employment agreement with a duration of at least 1 year, and are employed throughout the contract on at least a 0.20 FTE basis. Although precise information is not available, this appears to account for around 90 per cent of total non-administration staff.

[9] The assessment and scoring methods are described in more detail and critically evaluated in Buckle and Creedy (2019b).

[10] Two new categories C(NE) and R(NE) were introduced by the TEC for the 2012 and 2018 assessment rounds to signify if a researcher met the 'new and emerging' criteria. The score assigned by the TEC to R(NE) was 0 in 2012 and 2018, the same as in 2003. The score assigned by the TEC to C(NE) was 2 in 2012, the same as for C, and 4 in 2018 (New Zealand Tertiary Education Commission, 2019, p. 13). For the purposes of this paper the score assigned to C(NE) in 2018 is set equal to 2, to ensure consistency over time.

[11] The anonymised data used in this study are not publicly available and were provided by the NZ Tertiary Education Commission (TEC) following a confidentiality agreement.

gender, research subject area, university of employment, and FTE status, including whether the researcher exited or entered the entire NZ university system between rounds or transferred to or from another NZ university.

3. Summary of transitions of university researchers

Transition matrices (flows from rows to columns) summarising transitions of researchers between research quality categories for all universities combined, over 2003 to 2012 and 2012 to 2018, are shown in Table 1. The proportions of FTEs remaining in the same QC (the diagonal entries in the matrix) are highlighted in bold. Table 2 summarises the changes in the distribution of QCs between assessment rounds.

Table 1. Matrices of transition proportions: all universities 2003 to 2018

	Category in 2012					
Category in 2003	A	B	C	R	Exits	Total FTE
A	**0.531**	0.151	0.005	0	0.313	423.55
B	0.178	**0.373**	0.086	0.001	0.362	1689.16
C	0.029	0.254	**0.223**	0.011	0.483	2212.23
R	0.003	0.061	0.187	**0.046**	0.702	2206.19
Entrants	0.076	0.352	0.515	0.057		3079.71
Total	832.13	2475.42	2639.16	303.99	3360.14	9610.84
	Category in 2018					
Category in 2012	A	B	C	R	Exits	Total FTE
A	**0.600**	0.125	0.005	0	0.272	832.13
B	0.180	**0.440**	0.079	0.002	0.299	2475.42
C	0.018	0.293	**0.285**	0.012	0.392	2639.16
R	0	0.078	0.321	**0.062**	0.539	303.99
Entrants	0.057	0.304	0.596	0.043		2969.33
Total	1158.62	2894.20	2818.85	182.91	2165.45	9220.03

Source: Authors' calculations using anonymised TEC data.

The largest exit rate during the period 2003 to 2012, at just over 70 per cent, was of those assessed as R-quality researchers in 2003. Table 2 shows they accounted for 46 per cent of total exits during that period. Table 1 also shows that the exit rate of Cs during 2012 to 2018, at 39.2 per cent, was higher than for As (27.2 per cent) and Bs (29.9 per cent). Table 2 shows the total exits of Cs during 2012 to 2018 accounted for 48 per cent of total exits.

There was a higher entry rate for As, Bs, and Cs in 2003 to 2012 compared to Rs. The highest entry rate is for Cs, at nearly 52 per cent. This is consistent with the change in reputational and financial incentives faced by universities and the need to substitute new researchers for the high rate of exit of Rs during 2003 to 2012. However, there is no evidence of a tendency for the entry rate of As and Bs to rise during 2012 to 2018 compared to the entry rate for Cs, which remained the dominant source of new entrants during 2012 to 2018, perhaps reflecting the relative scarcity of higher-quality researchers.[12] New Zealand has a small academic labour market, and universities draw heavily on academics from the northern hemisphere. The costs of relocation and salary differentials make the recruitment of higher-quality researchers difficult. Universities are also subject to the continued pressures generated by outside (non-university) opportunities and salaries, which differ among disciplines (Boyle, 2008; Xu, 2008). Importantly, these changes are consistent with the incentives created by the PBRFS, as demonstrated by Buckle and Creedy (2019a, 2020) and Buckle *et al.* (2021), who tested a range of hypotheses regarding university responses to the new environment.

Table 2. Exits, entrants and quality transformations as proportions of initial total FTEs

QC	2003 FTEs	Exits	Entrants	Trans.	2012 FTEs	Exits	Entrants	Trans.	2018 FTEs
A	0.065	0.039	0.076	0.047	0.133	0.105	0.057	0.062	0.164
B	0.259	0.182	0.352	0.048	0.396	0.342	0.304	0.041	0.410
C	0.339	0.318	0.516	-0.014	0.422	0.478	0.596	-0.089	0.400
R	0.338	0.461	0.056	-0.081	0.048	0.075	0.044	-0.014	0.026
Totals	6531.1	3360.1	3079.7	0	6250.7	2165.5	2969.3	0	7054.6

Source: Authors' calculations using anonymised TEC data.

The quality transformation rates of B, C and R into A researchers in both periods are also consistent with the PBRFS incentives. The transformation rate for Bs to As was about 18 per cent in both periods; for Cs it was close to 3 per cent in 2003 to 2012 and 2 per cent in 2012 to 2018. Similar patterns occur for the rates of quality transformation of Cs and Rs to Bs and, as expected, the transformation rate of Cs and Rs is higher for lower 'target' QCs. Importantly, the patterns of change differ between the two periods. The main sources of the difference in the second period are: a lower exit rate for all grades; a higher proportion of C-graded entrants but a lower proportion of R entrants; a tendency for a higher upward transformation rate for Bs, Cs and Rs; and a higher proportion remaining in the same QC.

In 2003, the number of R-graded researchers formed just under 34 per cent of the total. The rate of R exits between 2003 and 2012 was so large, and the rate of recruitment or entrants of Rs so low, that by 2012 the proportion of Rs to total researchers was only 5 per cent. This low stock

[12] Buckle and Creedy (2019a) evaluated whether the use of NE categories (described footnote 10) affected the probability of upward transformation, and therefore whether this distinction influenced recruitment rates of NE category Cs and Rs. They found the distinction for Cs had little value. But for R researchers, those who were NE generally experienced more upward movement than other Rs. This supports the suggestion that the PBRFS encouraged more careful selection of entry-level researchers.

of Rs in 2012, coupled with a continued low rate of R entrants between 2012 and 2018, meant the proportion of Rs was less than 3 per cent by 2018. Their exit rate between 2012 and 2018 remained high, at 54 per cent.

The proportion of As increased from 6.5 per cent in 2003 to 13.3 per cent in 2012, and to 16.4 per cent in 2018. The proportion of Bs increased from 25.9 per cent in 2003 to 39.6 per cent in 2012, and to 41.0 per cent in 2018. While changes in exit and entrance rates are part of the explanation, important components are the rates of transformation of retained Cs to Bs, and of Bs to As. The following section explores more precisely how *AQS*s are affected by the flows illustrated in Tables 1 and 2.

4. Determinants of research quality change

To identify the way in which the component flows combine to affect the *AQS* of a university or discipline group, first let n_0 and n_1 denote the number of individuals in a university at times 0 and 1 respectively, and assume for convenience that all are full-time employees. As above, G_i denotes the score attached to each person, *i*, depending on the Quality Category, QC. The four QCs have scores, g_k, (for k = 1,...,4), of 10, 6, 2 and 0 (for A, B, C and R researchers respectively). Hence if person *i* belongs to category *k*, the score is $G_i = g_k$. Finally, let Q_0 and Q_1 denote *AQS*s at times 0 and 1. By definition, the initial *AQS* is:

$$Q_0 = \frac{1}{n_0}\sum_{i=1}^{n_0} G_i \qquad (1)$$

Suppose X_k people exit from quality category, *k*, and E_k enter, belonging to quality category, *k*. Furthermore, define T_k as the net transformations of incumbent researchers into quality category, *k*. That is, T_k measures the transfers into *k* from all other categories, net of the transfers out of *k* into all other categories, so that $\sum_{k=1}^{4} T_k = 0$. Allowing for all entries, exits and transformations over the period, Q_1 is:

$$Q_1 = \frac{1}{n_0 + \sum_{k=1}^{4}\left(E_k - X_k\right)}\left(n_0 Q_0 + \sum_{k=1}^{4}\left(E_k - X_k + T_k\right) g_k\right) \qquad (2)$$

The proportional change in quality is thus:

$$\frac{\Delta Q}{Q} = \frac{Q_1 - Q_0}{Q_0} = \frac{1}{n_0 + \sum_{k=1}^{4}\left(E_k - X_k\right)}\left(\frac{1}{Q_0}\sum_{k=1}^{4}\left(E_k - X_k + T_k\right)g_k - \sum_{k=1}^{4}\left(E_k - X_k\right)\right) \tag{3}$$

Another way to express this is:

$$\frac{\Delta Q}{Q} = \frac{n_0}{n_1}\left[\frac{n_1 Q_1 - n_0 Q_0}{n_0 Q_0} - \frac{n_1 - n_0}{n_0}\right] \tag{4}$$

The two terms in square brackets in (4) are the proportional changes in the total score and the proportional change in the number of researchers in the university. The second term is thus a pure scale effect, while the first term reflects the precise combination of exits, entries and quality transformations which contribute to quality change. If the growth in scale is denoted, $\frac{\Delta n}{n} = \frac{n_1 - n_0}{n_0}$, (4) becomes:

$$\frac{\Delta Q}{Q} = \frac{1}{1 + \frac{\Delta n}{n}}\left[\frac{n_1 Q_1 - n_0 Q_0}{n_0 Q_0} - \frac{\Delta n}{n}\right] \tag{5}$$

Thus, other things equal, growth in university size has an unambiguously negative effect on *AQS* growth.

As mentioned in Section 3, an important feature of the incentives created by the NZ PBRFS is that responses depend strongly on the initial *AQS* of the university. For example, low-quality universities have relatively large numbers of R-rated researchers, encouraging a high exit rate of Rs. Higher-quality universities are able to retain their higher-quality researchers, and at the same time can more readily attract high-quality researchers from other universities in NZ as well as from outside the system. In addition, universities with high *AQS*s may be able to attract strong younger researchers, who enter as C or even R types, but are capable of progressing more rapidly to higher levels.

The PBRFS scoring system implies that, for example, a university with an initial *AQS* that is below 2 can increase its average quality by employing more C-type researchers. But a university with an *AQS* above 2 reduces its average quality by employing more Cs: they will wish to be confident that those who do enter the university are capable of subsequently raising their score. The fact that the attractiveness of C-type researchers varies with the *AQS* means not only that there are differences among universities at any time, but their ability to raise their *AQS* further via recruitment practices is likely to change over time as their *AQS*s change.

The question then arises of whether these characteristics suggest anything about convergence. The structure revealed in (3) is too complex to provide a simple analytical expression relating *AQS* changes to initial *AQS* levels. However, differential rates of exit, entry and quality transformation can contribute towards convergence for several reasons. For example, there is an upper limit to the extent to which exits can continue to contribute to improving a university or discipline *AQS*: as the number of low-quality researchers is reduced, the scope to improve an *AQS* from exits diminishes.

A similar argument could be made for the marginal effects of transformations (*T*), and there may also be diminishing benefits from investing in initiatives that improve the research environment and skills of incumbent researchers. For entrants, there is a diminishing effect from a university's budget constraint, as well as from constraints imposed by other university requirements (such as teaching and administration staffing requirements). For these reasons, the effects of exits, entrants and transformations on the rate of improvement of research quality of a university or discipline can be expected to display diminishing marginal productivity analogous to those evident in models of economic growth convergence.[13] The following section therefore uses a 'reduced form' specification that is familiar from other growth contexts, while Appendix B uses an illustrative numerical example to demonstrate that such a form can indeed arise from the characteristics of observed *AQS* transitions.

5. Growth rates of Average Quality Score, β-convergence and σ-convergence

A standard form of logarithmic regression specification between *AQS* changes and initial *AQS* was used by Buckle *et al.* (2020) to test for β-convergence over the period 2003 to 2012, whereby:

$$\log AQS_{ijt} - \log AQS_{ijt-1} = c + \beta \log AQS_{ijt-1} + \varepsilon_{ijt} \tag{6}$$

The left-hand side of (6) measures the (annualised) proportional AQS growth rate for university *j*, and discipline *i*, where *t* and *t*-1 refer to the two PBRFS dates.[14] This enables the systematic

[13] See, for example, Abramovitz (1986), Baumol (1986), Barro and Sala-i-Martin (1991), Dowrick and Gemmell (1991) and Quah (1993).

[14] Buckle *et al.* (2020) did not need to annualise the growth rates because only one period was available. Following Buckle and Creedy (2020), the empirical analysis is based on all academic subjects, collected into nine disciplines: medicine, engineering, core science, management, accounting finance & economics, humanities, agriculture, law and education.

component of change to be separated from other influences, including university-specific fixed effects and random shocks.[15]

The addition of a third PBRFS round, in 2018, allows testing of the convergence rate using a longer lag structure. Thus:[16]

$$\log AQS_{ijt} - \log AQS_{ijt-1} = \gamma + \beta_1 \log AQS_{ijt-1} + \beta_2 \log AQS_{ijt-2} + \varepsilon_{ijt} \quad (7)$$

In what follows, t, t-1 and t-2 refer to 2018, 2012 and 2003. The full convergence effect, β, is measured by $\beta = (\beta_1 + \beta_2)$. Convergence tests can also be conditioned on a vector of additional variables, including the number of staff FTEs, the median age and the gender ratio of researchers by university and discipline.

Testing for differences across universities and disciplines in the growth (and convergence or divergence) of their *AQS*s, involves testing for the inclusion or exclusion in regressions of shift dummy variables, where $D_i = 1$ for university i, and is zero otherwise. Slope dummies, S_i, equal to $D_i \log AQS_{it-1}$ are also added. Similar dummies are defined for discipline groups. The parameters γ and $\beta = (\beta_1 + \beta_2)$ in (7), along with their university-specific and discipline-specific equivalents, therefore respectively capture autonomous *AQS* growth and the rate of convergence ($\beta < 0$) or divergence ($\beta > 0$) of *AQS*s for each university and discipline. The parameter, β, may be interpreted as the 'full' rate of convergence over the whole period, including any university or discipline fixed effects.

The approach begins with all dummy variables included: 2×8 university shift and slope dummies and 2×9 discipline equivalents. These are progressively eliminated using the 'general-to-specific' (*Gets*) approach of Campos, *et al.* (2005), Castle *et al*. (2011) and Hendry and Doornik (2014), whereby the variable with the lowest t-ratio is omitted first.[17] The regression is then re-run in a sequential process, until the most parsimonious specification of the data-generating process is obtained. This effectively treats the null hypothesis as $\gamma_i \neq \gamma_j \neq \gamma$ and

[15] Random shocks in this case might include, for example, the 2010-11 Canterbury earthquakes which may have affected the ability of Canterbury and Lincoln universities to recruit staff after 2011. In NZ's small university system this may have indirectly affected recruitment practices, including other universities recruiting higher-quality staff from CU and LU.
[16] This specification is consistent with one having the lagged (logarithm) of the 2012 *AQS*, and the growth from 2003 to 2012 (that is, the difference in the logarithms of the *AQS*s), on the right-hand side. The interpretation is that growth from 2012 to 2018 depends on the *AQS* level in 2012 and the previous annualised growth rate experienced from 2003 to 2012.
[17] Campos *et al*. (2005, p. 2), for example, summarise the *Gets* approach as follows: '1. Ascertain that the general statistical model is congruent. 2. Eliminate a variable (or variables) that satisfies the selection (i.e., simplification) criteria. 3. Check that the simplified model remains congruent. 4. Continue steps 2 and 3 until none of the remaining variables can be eliminated'.

$\beta_i \neq \beta_j \neq \beta$, against the alternative of common values of γ and β across universities and disciplines.

Table 3. General-to-Specific modelling of AQS growth

	All universities and disciplines			(1) All universities; then (2) all disciplines		
Unit	Dummy	Order omitted	t-ratio	Dummy	Order omitted	t-ratio
LU	*D*	17	-1.27	*D*	16	1.73
	S	19	1.09	*S*	1	0
AU	*D*	15	1.25	*D*	4	0.20
	S	7	-0.29	*S*	3	-0.47
CU	*D*	26	0.07	*D*	5	0.46
	S	25	-1.50	*S*	6	-0.33
OU	*D*	14	0.90	*D*	7	1.03
	S	13	-0.98	*S*	8	-0.22
WU	*D*	23	1.66	*D*	10	0.20
	S	24	-1.12	*S*	9	-0.97
VUW	*D*	9	-0.63	*D*	2	0.32
	S	10	0.17	*S*	12	-1.14
MU	*D*	1	0	*D*	15	0.36
	S	6	-0.23	*S*	14	-1.43
AUT	*D*	28	1.77	*D*	13	1.33
	S	29	-1.75	*S*	11	-0.86
Medicine	*D*	30	**-2.41**	*D*	2	-0.05
	S	2	0.03	*S*	9	-1.50
Engineering	*D*	12	0.71	*D*	3	0.36
	S	3	-0.05	*S*	1	-0.02
Core Science	*D*	33	0.30	*D*	17	0.30
	S	32	**-2.49**	*S*	16	-2.49
Management	*D*	5	0.19	*D*	8	-0.23
	S	11	0.64	*S*	7	-1.22
AFE	*D*	16	1.37	*D*	5	0.57
	S	-	**-3.48**	*S*	-	**-3.48**
Humanities	*D*	4	0.04	*D*	15	2.21
	S	21	1.47	*S*	4	-0.23
Agriculture	*D*	18	-0.93	*D*	12	-1.74
	S	22	1.44	*S*	13	1.44
Law	*D*	20	1.19	*D*	14	2.27
	S	8	-0.49	*S*	6	-0.81
Education	*D*	31	-2.3	*D*	11	1.75
	S	27	**2.57**	*S*	10	1.66

Notes: *D* = shift; *S* = slope; LU=Lincoln University, AU=Auckland University, CU=Canterbury University, OU=Otago University, WU=Waikato University, VUW=Victoria University of Wellington, MU=Massey University, AUT=Auckland University of Technology.

Following the *Gets* approach, the convergence variables, logAQS_{2012} and logAQS_{2003}, always passed relevant *t*-tests, while dummy variables were progressively eliminated based on parameter *t*-tests. Table 3 shows *t*-ratios associated with the shift (*D*) and slope (*S*) dummy variables for each university and discipline added to regressions on (7), and the order in which they are omitted. Left-hand columns report results based on initial regressions including *all* dummies.

As a check, right-hand columns report similar results but for initial regressions that include either all university dummies or all discipline dummies. In both cases the table shows the *t*-ratio associated with a given dummy in the regression immediately prior to it being omitted. For example, in the left-hand columns of Table 3, the first variable eliminated was the shift dummy for Massey University (MU) with a *t*-value of 0.00. The regression was re-run omitting this variable. This led to the slope dummy for medicine being identified as the lowest *t*-ratio and eliminated (t = 0.03). This process was repeated until only variables with *t*-ratios > $|3|$ were retained.[18] The only dummy variable meriting retention in the regression after this process is the slope dummy variable for the Accounting, Finance and Economics (AFE) discipline group, with a t-ratio of -3.48.[19] The same final outcome is obtained using the approach in the right-hand columns which, for example, tests the null hypothesis, $\beta_i \neq \beta$, while maintaining $\beta_j = \beta$, and *vice versa*.

Details of the final regression are reported in Table 4.[20] These reveal a strong common initial rate of β-convergence across all universities and disciplines (except AFE) of β_1 = –0.1167.[21] The initial AFE convergence rate, at β_1 = –0.1321 (–0.1167 – 0.0154), is quantitatively similar to, if statistically different from, the average rate of –0.1167 across all disciplines. There are

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[18] A critical *t*-ratio = 3 was chosen following Castle *et al.* (2011) and Castle and Hendry (2014) who argue that substantial pre-testing and variable selection from many possible models increases the risk of retaining irrelevant variables. For example, with a critical significance level for *t*-tests of $c_\alpha = 0.05$, there is a 1 in 20 chance of an irrelevant variable being retained (with a threshold t > 2) in the model on average. However, for $c_\alpha = 0.01$ ($t_\alpha \approx 2.6$) this becomes 1 in 100, and $c_\alpha = 0.001$ ($t_\alpha \approx 3.35$) implies 1 in 1000. Hence t_α between 2.6 and 3.35 substantially reduce the risk of a false positive. Castle and Hendry (2014) recommend setting α = min(1/N, 1/T, 1%).

[19] Table 3 also indicates that if a more conventional t > 2 was used to retain dummy variables, a shift dummy for Medicine (t = 2.41), a slope dummy for core Science (t = 2.49) and a slope dummy for Education (t = 2.57) would be retained.

[20] Regressions in Table 4 use 87 observations: 70 for the 8 universities and 9 disciplines within universities, less two missing observations for Law and Education at Lincoln, plus 17 AQS_{ij} values, averaged across all universities and all disciplines. This enables parameters for each university's growth and convergence to be compared directly with the average across all universities or disciplines rather than adopting one university and discipline as the omitted variable. However, adjusted-R^2s must be interpreted cautiously since they are somewhat inflated by the inclusion of individual observations and their cross-university or cross-discipline averages.

[21] The estimated common convergence rate above is an annual rate, implying a convergence rate over the six years, from 2012 to 2018, of –0.7002, which compares with –0.722 reported by Buckle *et al*. (2020) for 2003 to 2012 (and where lagged *AQS* values could not be included).

several possible reasons why the AFE discipline group could have a different estimated rate of convergence. This may reflect differences in international market conditions and rates of staff turnover for AFE researchers (see, for example, Boyle, 2008; Xu, 2008; Ehrenberg, *et al*., 1991), a difference in attitudes and responses to the PBRFS incentives (Shin and Cummings, 2010), differences in the availability of contestable research funding for AFE researchers, or a difference in assessment standards adopted by the PBRFS assessment panel for the AFE group. In the absence of suitable data, these issues cannot be explored here.

Table 4. Final regression results for AQS growth

	Coefficient	Standard Error	*t*-value	95% Confidence Interval	
$\log AQS_{2012}$	-0.1167	0.0116	-10.09	-0.1396	-0.0937
$\log AQS_{2003}$	0.0220	0.0048	4.55	0.1124	0.0316
$D_{AFE}\times\log AQS_{2012}$	-0.0154	0.0044	-3.48	-0.0242	-0.0066
Constant	0.1699	0.0140	12.13	0.1420	0.1978
Long-run convergence[22]	-0.0947	0.0086	-10.99		
R^2 = 0.605	Adj-R^2 = 0.591		F (3, 83) = 42.33		Obs. = 87

Notes: Dependent variable: change in log(AQS), 2012-2018. $D_{AFE}\times\log AQS_{2003}$ is a slope dummy variable for the Accounting, Finance and Economics discipline (AFE). Adding D_{AFE} to the regression, to confirm that its prior exclusion was justified, confirmed that the regression is clearly preferred (the *t*-ratios on both AFE dummy variables were less than $|2|$).

Table 4 suggests that the inclusion of $\log AQS_{2003}$ in the specification is statistically justified and slightly reduces the longer-run annual convergence rate; with $\beta_2 = 0.022$ and hence $\beta = -0.0947$ ($t = -10.994$). The positive sign on $\log AQS_{2003}$ reflects the fact that the degree of convergence in the first period is negatively associated with convergence in the second period, thereby modifying the full-period degree of convergence. This slightly slower rate of convergence when estimated over the whole 2003 to 2018 period is unsurprising given the rapid estimated convergence rates, such that by 2018, average research quality scores were much closer across universities and disciplines than they had been in 2003 when the PBRFS was introduced.

The value of β, while small in absolute terms, implies a high rate of convergence, in terms of differential average growth rates, conditional on the initial *AQS.* These are clearly illustrated in the cross-plot of the 87 individual observations in Figure 1, which shows the relationship between $\log AQS_{2012}$ and actual *AQS* growth. The $\log AQS$ observations in 2012 can be seen to range from as low as around 0.5 ($AQS \approx 1.6$) to highs around 1.9 ($AQS \approx 6.8$). Similarly,

[22] Long run convergence standard errors are obtained by re-parameterising equation (7) such that RHS variables include $\ln AQS_{2012}$ and ($\ln AQS_{2012} - \ln AQS_{2003}$), instead of $\ln AQS_{2012}$ and $\ln AQS_{2003}$, giving estimates of ($\beta_1 + \beta_2$) and β_2 respectively.

differences across research units in the rate of growth of *AQS* over the 2012 to 2018 period are substantial, ranging from negative annual growth rates of -0.06 to large positive growth of 0.12. The degree of β-convergence therefore reflects relatively rapid convergence, or 'catch-up'.

Figure 1. Actual AQS growth and initial AQS

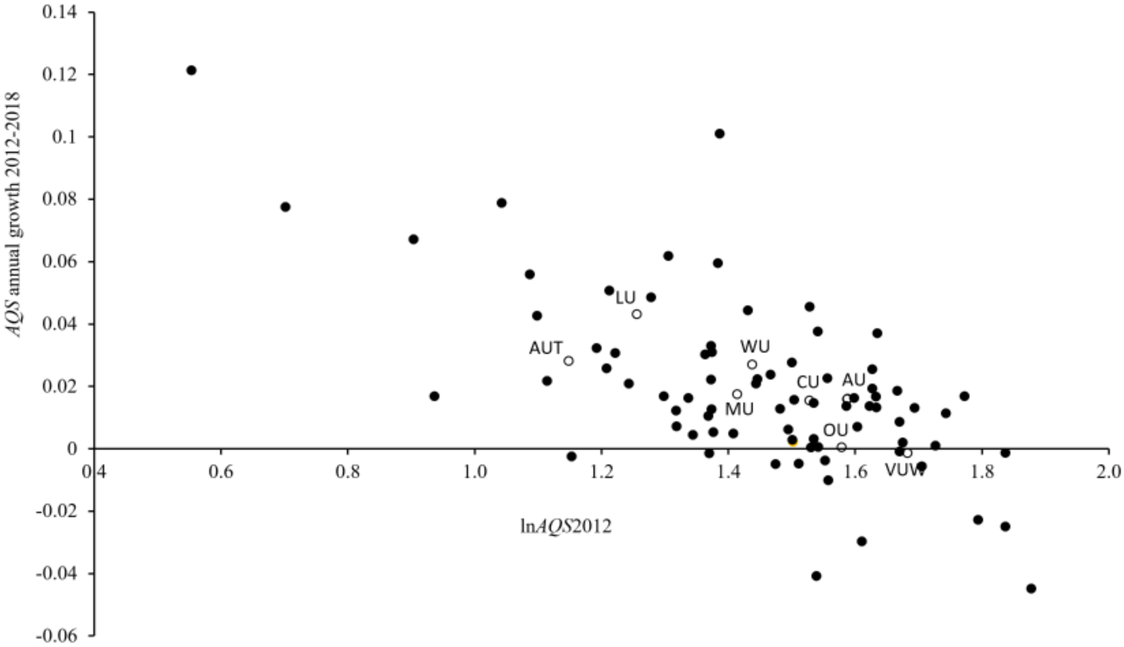


Figure 2. Expected AQS growth and initial AQS

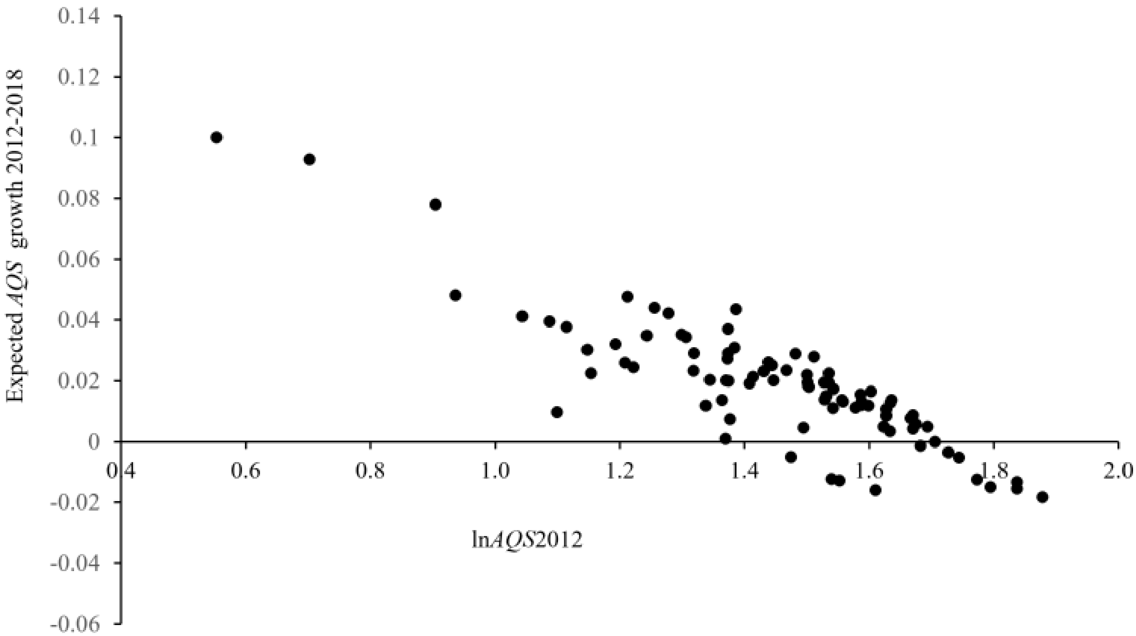
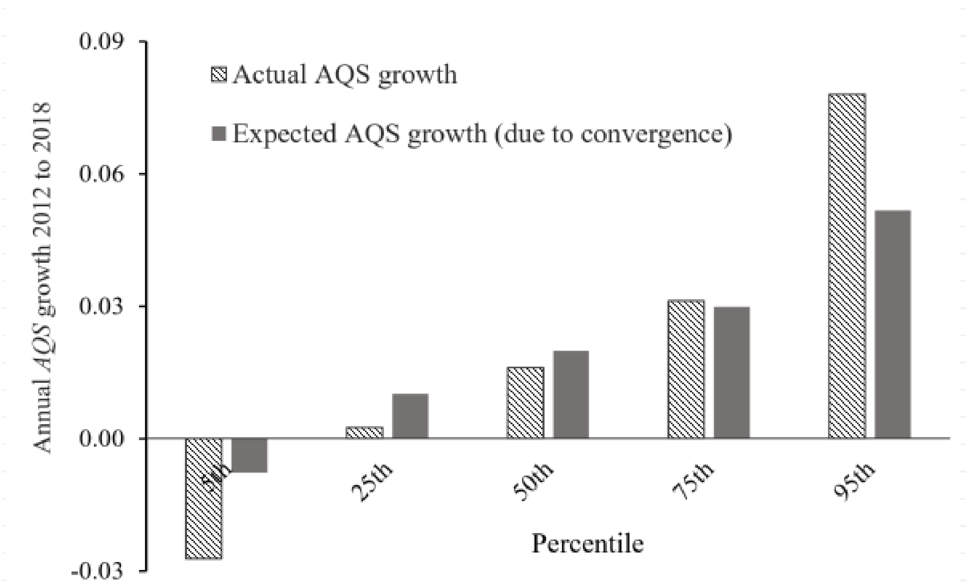


Figure 1 reveals the negative relationship across individual research units, implying a strong β-convergence tendency. In addition, the highlighted observations (white dots) for average values (across disciplines) within the each of the eight universities, confirm a convergence tendency at the aggregated university level. Thus, for example, AUT and Lincoln University (LU) had the lowest initial *AQS* values and the fastest *AQS* growth, whilst the initially-leading university, VUW, had the slowest (near zero) *AQS* growth.

Based on the regression in Table 4, Figure 2 shows the relationship between $\log AQS_{2012}$ and expected values of *AQS* growth from the regression result. This is not simply a straight line, since values of $\log AQS_{2003}$ vary across the observations shown. Nevertheless, the dominant convergence relationship between $\log AQS_{2012}$ and expected *AQS* growth is clear in Figure 2, despite the small lagged divergent contribution from $\log AQS_{2003}$. A small additional source of variation observed in Figure 2 arises from the slightly different convergence parameter applicable to AFE.

Figure 3 compares actual and expected *AQS* growth at various points in the distribution from the 5th to the 95th percentile. This reveals a generally good fit across the distribution of *AQS* growth (2012 to 2018) observations, especially around the median. Unsurprisingly, expected values fit less well at the 5th and 95th percentiles, but nevertheless perform well, for example capturing around 67 per cent of the large actual *AQS* growth rates at the 95th percentile (0.052/0.078), but under 30 per cent at the 5th percentile.

Figure 3. Actual and expected AQS growth at percentiles



The effects of control variables, including their potential impacts on convergence parameters, were tested by adding three variables to equation (7). These were: the initial number of staff FTEs in a university-discipline unit; its gender balance (female staff share); and staff median age. These variables were added individually and in combination, but none revealed any statistically significant effects, using conventional confidence intervals.

Overall convergence or divergence in *AQS* scores is measured by σ-convergence, indicating whether the distribution of *AQS*s across research units is becoming more or less dispersed. As discussed in Buckle *et al*. (2020), $\beta < 0$ does not necessarily imply σ-convergence, which also depends on the error variance, σ_ε in (7). Table 5 reports the variances of log*AQS* across universities and disciplines separately and combined, and for each discipline within universities. This shows that there were substantial reductions in the overall dispersion of log*AQS* between 2003 and 2018 for all groups: for all universities and disciplines combined and for each discipline within universities.[23]

However, the change in variances differs substantially between the earlier period 2003 to 2012 and the later period, 2012 to 2018. The largest declines in dispersion occur during 2003 to 2012, whereas during 2012 to 2018 changes in variances are much smaller and are not lower in all cases. For all universities combined, the variance is more than halved during 2012 to 2018, but for disciplines there is little change. For disciplines within universities, the decline of the variance for Massey disciplines is as large as for the earlier period, but for the other universities there is very little change, with half experiencing a small increase and the others a small decrease or no change.

Thus a strong common rate of β-convergence across all university and discipline units during 2012 to 2018 did not necessarily translate into an overall decline in dispersion across all units, with differences in σ-convergence observed across periods. Whereas substantial σ-convergence is observed for all groups during the initial PBRFS phase in 2003 to 2012, there is a mix of σ-convergence and σ-divergence during 2012 to 2018, with a relatively small reduction in variances after 2012. This partly arises from the relatively low variance of log*AQS* achieved by 2012.

[23] When AUT (which had a much lower *AQS* in 2003 than other universities) is excluded the variance still declines but by much less than when AUT is included. Similarly, When Education (which had a much lower *AQS* in 2003 than other disciplines) is excluded the variance still declines but by much less than when Education is included.

Table 5. Variances of logarithms of AQS, 2003, 2012 and 2018

Groups for which variances are estimated:	2003	2012	2018	Obs.
All universities	0.2280	0.0283	0.0121	8
All disciplines	0.0850	0.0135	0.0138	9
All universities and disciplines	0.1541	0.0211	0.0131	17
Across disciplines (within universities):				
AUT	0.1400	0.0161	0.0202	9
Lincoln	0.0935	0.0632	0.0598	7
Massey	0.1584	0.0866	0.0185	9
Auckland	0.0911	0.0084	0.0175	9
Canterbury	0.2358	0.0261	0.0235	9
Otago	0.0843	0.0189	0.0189	9
Waikato	0.0873	0.0071	0.0101	9
VUW	0.1801	0.0295	0.0333	9
Across universities (within disciplines):				
Medicine	0.3625	0.0353	0.0274	8
Engineering	0.2442	0.0243	0.0155	8
Core science	0.3816	0.0259	0.0258	8
Management	0.1690	0.0429	0.0241	8
Acc Fin Eco	0.3203	0.0815	0.0136	8
Humanities	0.2236	0.0401	0.0144	8
Agriculture	0.1009	0.0230	0.0232	8
Law	0.4163	0.1881	0.0360	7
Education	0.1413	0.0265	0.0241	7
All university-discipline units	0.3554	0.0636	0.0346	70

Source: Authors' estimates using data from Table A1, Appendix A.

6. Contribution of exits, entrants and quality transformations to *AQS* changes

The previous section estimated the extent of research-quality convergence of universities and discipline groups, although it did not directly consider the precise sources of the *AQS* growth in terms of the turnover of staff and their quality transformation. This section examines these sources and their dynamics, revealing how the separate contributions of exits, entrants and quality transformations of incumbent researchers combine to generate overall convergence. The analysis uses a decomposition method to identify the contributions of these three components, for universities and discipline groups.

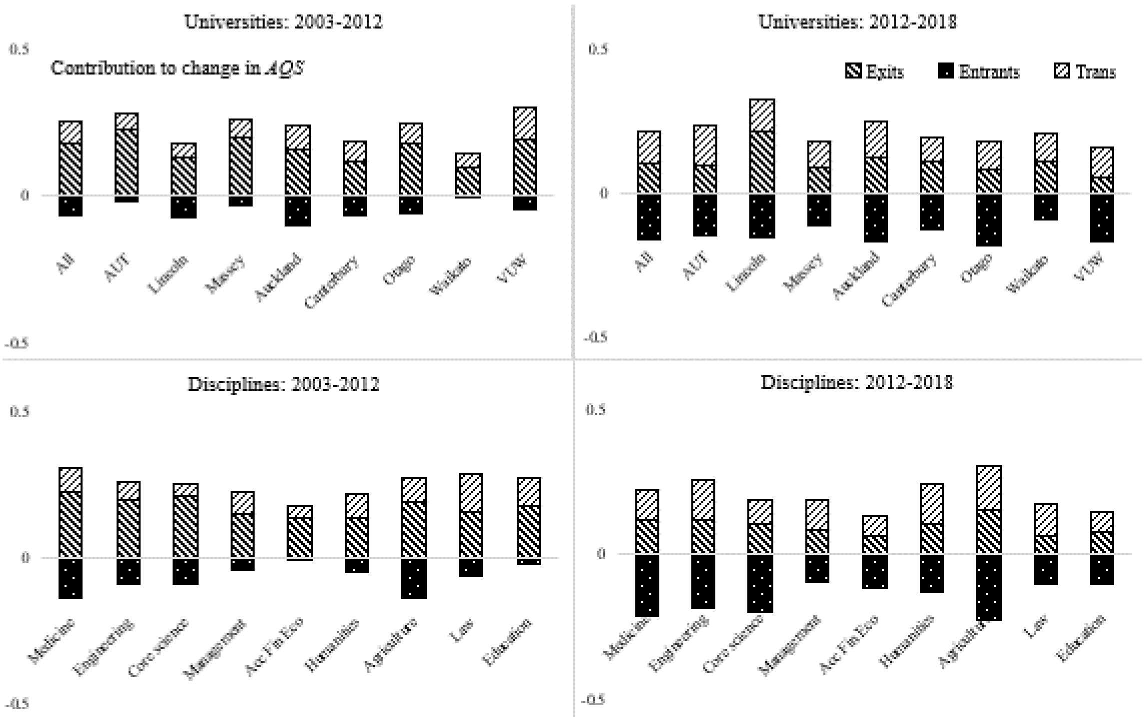
The required decomposition can be obtained by suitably modifying the relevant transition matrix, as follows. Let the initial and final *AQS* for the specified group be denoted by $Q1$ and $Q2$. The aim is to decompose $Q2$-$Q1$ into components that measure the separate impact on the change in *AQS* of exits, entrants and quality transformations. An *AQS* can be calculated for the final period, using a counterfactual assumption of no entrants into any category, denoted $Q3$.

Furthermore, it is possible to obtain an alternative counterfactual *AQS* in the final period, by setting all exits and entrants to zero: this is denoted *Q*4. The counterfactual of no exits is applied by supposing that those recorded as exiting remain in the quality category in which they were placed in the initial period: that is, the diagonals of the flow matrix are augmented by the number of (FTE) exits. The difference, *Q*4-*Q*1, therefore reflects the effect of quality transformations made by those who remain in the system (since, in calculating *Q*4, those who actually exit are assumed to remain on their respective diagonal). The difference, *Q*3-*Q*4, reflects the separate effect of exits. Finally, the difference, *Q*2-*Q*3, measures the effect of entrants. These are combined to give:

$$Q2 - Q1 = (Q2 - Q3) + (Q3 - Q4) + (Q4 - Q1) \qquad (8)$$

These contributions can be derived for the entire university system, and for any unit within the system. Figure 4, derived using the data in Table A1, illustrates the separate annual average contributions to the changes in *AQS* of exits, entrants and quality transformations for all universities combined, each university and discipline group. The contributions for each discipline within each university are shown in Figure A1 in Appendix A.

Figure 4. Average annual contributions to AQS growth of exits, entrants and quality transformations



Notes: Derived from Appendix A, Table A1

It is evident from Figure 4 that, for the university system as a whole and for each university and discipline, the net impact of exits is always positive, the net impact of entrants is always negative, and the net impact of quality transformations is always positive. This pattern prevails in both periods, although the sizes of the average annual contributions change. In the second period the positive average annual contributions from quality transformations are larger (0.08 in 2003-2012 and 0.12 in 2012-2018) and from exits are smaller (0.17 in 2003-2012 and 0.11 in 2012-2018). The negative average annual contribution from entrants increases during the second period (-0.07 in 2003-2012 and -0.16 in 2012-2018).

The characteristics for separate disciplines within each university are shown Figure A1 in Appendix A. This reveals greater diversity in the level of contributions and the changes between the two periods than is evident for the more aggregated university and discipline groups shown in Figure 4. Nevertheless even for disciplines within universities, in both periods there are very few negative contributions from quality transformations and exits, as shown in Table A1.

A word of caution is necessary in interpreting the negative contribution of entrants observed above. This contribution, $Q2$-$Q3$, measures the difference between the final *AQS* and that which would result from having no entrants, and relates only to the *AQS* values in the final period. Hence a negative value of $Q2$-$Q3$ suggests that entrants on average are, by the second period, of lower-quality than the incumbents in the second period. And of course, incumbents are typically subject to positive net transformations over the period. However, it does not necessarily mean that the entrants do not contribute positively to a higher overall *AQS*, as their contribution is positive so long as the average quality of entrants is higher than the overall first-period *AQS*.

Further details of the contributions are provided in Table 6, for all universities combined. This shows the beginning and end-of-period *AQS*s of various groups, and differences between the *AQS*s of the groups. The table shows how the different groups have contributed to the overall change in the *AQS*. The *AQS* of exits during 2003 to 2012, of 2.12, was substantially lower than the *AQS* of all researchers, of 2.88, in 2003. In 2003 the *AQS* of those who remained incumbent in the system was 3.68, which was 0.80 higher than the average of all researchers. They improved considerably to 5.18. Interestingly, the entrants during this period had an *AQS* in 2003 of 3.90. Although this was lower than the *AQS* of all researchers in 2012, of 4.55, it was higher than the *AQS* of all researchers in 2003. Therefore, the net effect of entrants was to contribute to an improvement in the score from 2003, of 1.02, but this contribution to the improvement in *AQS* was lower than that of incumbents, which was 2.3.

The second period differs in important ways from the first. The exits during this period had an *AQS* lower than that of all researchers in 2012. However, the difference was about half of the corresponding difference in the earlier period. Entrants, on the other hand, had a much lower score in 2018 than did entrants in the earlier period (by 2012) and was also lower than the *AQS* for all researchers at the start (2012) of this second period. Hence, the net effect of entrants during 2012 to 2018 was to reduce the *AQS* of all researchers in 2018, from what it would otherwise have been (that is, with no entrants). The *AQS* of entrants in 2012 was 0.97 lower than the score of all researchers in 2012, contrasting with an *AQS* of incumbents which was 1.31 higher than the average of all researchers at the start of the period. In addition, the *AQS* of entrants in 2012 was actually lower than the *AQS* in 2012 of those who exited the system during the second period.

The positive contributions of exits and quality transformations to the growth in *AQS*s are consistent with the new incentives created by the PBRFS. These encouraged universities to remove lower-quality researchers and to retain higher-quality and promising researchers considered more likely to transition to a higher QC over time. The positive net impact of quality transformations reflects decisions to attract and retain good researchers who improve over time. This net positive effect captures the mixture of those who improve and those who decline in quality while remaining within the institution. There were clearly diminishing gains from the positive net transformations of incumbents during the second period compared with the first.

Table 6. AQSs for exiting, entering and incumbent researchers

Period		Differences in *AQS* compared to:		
2003 to 2012	*AQS*	All in 2003	Incumbents in 2003	Incumbents in 2012
AQS all researchers in 2003	2.88			
AQS of incumbents in 2003	3.68	0.80		
AQS of incumbents in 2012	5.18	2.30	1.50	
2003 *AQS* of exiting researchers	2.12	-0.76	-1.56	-3.06
2012 *AQS* of entering researchers	3.90	1.02	0.22	-1.28
AQS of all researchers in 2012	4.55			
2012 to 2018		All in 2012	Incumbents in 2012	Incumbents in 2018
AQS of all researchers in 2012	4.55			
AQS of incumbents in 2012	4.82	0.27		
AQS of incumbents in 2018	5.86	1.31	1.04	
2012 *AQS* of exiting researchers	4.06	-0.49	-0.76	-1.80
2018 *AQS* of entering researchers	3.58	-0.57	-1.24	-2.28
AQS all researchers in 2018	4.91			

*Notes:AQS*s derived from data in Table 1. Incumbents refers to researchers who remained within the university system during the period and participated in the beginning and end of period assessment rounds.

The average annual contribution of exits, although also on average positive in both periods, is smaller in the second period. This reflects the situation where the removal of a very high proportion of R researchers during the first period reduced the scope for similar *AQS* gains from this source during the second period, as shown in Table 2. During the second period, the proportion of exits by higher-quality researchers increases substantially; see Table 2 above.

The contribution of entrants to growth in university *AQS*s clearly deteriorated during the second period compared with the first period: their *AQS* was lower than that of entrants in the first period, and lower than the *AQS* of all researchers at the start of the second period, and of exits during that period. It clearly became increasingly more difficult to recruit entrants above the average quality: on the difficulty of recruiting higher-quality researchers, see also Section 3 above.[24]

Table 7 reports standard deviations of the separate average annual contributions of exits, entrants and quality transformations to changes in *AQS*. These standard deviations are similar in both periods for all universities and disciplines. The changes in standard deviations across disciplines within universities (shown in the lower section of the table) are more diverse, as observed in Section 5 for changes in variances of logarithms of *AQS*s across disciplines within universities.

Table 7. Standard deviations of the X, E & T average annual contributions to AQS growth

	2003-2012			2012-2018		
	Exits	Entrants	Trans	Exits	Entrants	Trans
Universities:	0.045	0.031	0.018	0.047	0.033	0.020
Disciplines:	0.036	0.046	0.026	0.029	0.053	0.030
AUT disciplines:	0.073	0.105	0.013	0.076	0.175	0.068
Lincoln disciplines:	0.106	0.071	0.053	0.092	0.166	0.040
Massey disciplines:	0.081	0.066	0.026	0.049	0.067	0.072
Auckland disciplines:	0.034	0.060	0.040	0.079	0.053	0.047
Canterbury disciplines:	0.045	0.077	0.035	0.074	0.093	0.040
Otago disciplines:	0.070	0.106	0.059	0.076	0.064	0.065
Waikato disciplines:	0.043	0.050	0.047	0.088	0.073	0.053
VUW disciplines:	0.083	0.062	0.036	0.053	0.117	0.080

Source: Authors' calculations using data from Appendix Table A1.
Note: The standard deviations are of the average annual contributions of X, E and T to *AQS* growth.

[24] The lower average quality of entrants appears not to be dominated by hiring younger new PhD graduates; see Buckle, *et al* (2021).

7. Convergence properties of contributions to *AQS* growth

This section evaluates how the separate components of *AQS* growth (entry, exit and quality transformation), summarised in Section 6, contribute to the convergence properties observed for *AQS* growth as a whole. That is, did initially lower-quality units catch-up on higher-quality units largely via improvements to retained staff, or via the removal of low-quality staff and/or recruitment of higher-quality new staff? While results reported in Section 6 revealed negative effects on *AQS* growth from new entrants (that is, comparing their second-year *AQS* with that of incumbents), they could have contributed to cross-unit quality *convergence*. For example, to help catch-up on other units, some universities or disciplines may have used a strategy of quality improvement for retained staff, even if they had limited ability, or made little attempt, to use exits and entrants for this purpose, or *vice versa*. The previous section revealed substantial variation across universities and discipline groups and across disciplines within universities in the contributions of these different components.

To examine the influences on convergence of exits (*X*), entrants (*E*) and quality transformations (*T*), a two-stage process was followed. First, regressions of equation (7), including control variables, were estimated: statistically insignificant controls were progressively eliminated. This suggested at most one control variable, each unit's initial median age of staff, Age_{2012}, with a significant effect on *AQS* growth, but only for *E* and *T*. Results are reported in columns (i) to (iii) of Table 8. Second, the previous general-to-specific process was followed, starting with all dummy variables and Age_{2012} included, and eliminating insignificant variables in turn. This yielded the 'final' regressions reported in columns (iv) to (vi) of Table 8.[25]

Allowing for the possibility of different rates of convergence across universities and disciplines, final results in columns (iv) to (vi) suggest that all three components of *AQS* growth contributed towards overall convergence, with β_1 negative in all cases, and with additional negative effects from β_2 for quality transformations, *T*. Long-run convergence parameters also confirm negative effects in all three cases. In the case of *X* and *T* these are robustly identified (*t*-ratios exceed $|3|$), while for *E* the estimate (–0.0646) is significantly negative at the 10 per cent level. However, estimated magnitudes suggest that the largest effects on *AQS* growth are from *E* and *T* (around –0.065 to –0.068), with estimated convergence effects for *X* smaller at –0.028.

[25] Based on regressions (iv) to (vi), re-testing the inclusion of all control variables by adding them to those regressions did not support the inclusion of any.

Table 8. Regression results for AQS growth components, X, E and T

	------------ Stage 1 results ------------			------------ Stage 2 results ------------		
	(i)	(ii)	(iii)	(iv)	(v)	(vi)
	Exits	Entrants	Trans.	Exits	Entrants	Trans.
$\log AQS_{2012}$	-0.0625 (0.0112)**	-0.0847 (0.0591)	-0.0479 (0.0137)**	-0.0433 (0.011)**	-0.1230 (0.0506)**	-0.0424 (0.0119)**
$\log AQS_{2003}$	0.0160 (0.0047)**	0.0650 (0.0273)	-0.0190 (0.0055)**	0.0152 (0.0057)**	0.0584 (0.0233)**	-0.0257 (0.0042)**
Age_{2012}	†	0.0068 (0.0030)**	-0.0024 (0.0006)**	†	†	-0.0014 (0.0005)**
D_{MU}					-0.0793 (0.0249)**	0.1027 (0.0231)**
D_{LU}						-0.0185 (0.0059)**
D_{AUT}				0.1802 (0.046)**		
$D_{MU}\times\log AQS_{2012}$						-0.0810 (0.0167)**
$D_{LU}\times\log AQS_{2012}$				0.0185 (0.0048)**		
$D_{AUT}\times\log AQS_{2012}$				-0.1468 (0.0387)**		
D_{Edu}						-0.2612 (0.0389)**
D_{Ag}					1.4487 (0.4731)**	
D_{Med}					-0.1004 (0.0300)**	
$D_{Edu}\times\log AQS_{2012}$						0.1795 (0.0298)**
$D_{Ag}\times\log AQS_{2012}$					-0.9478 (0.2857)**	
$D_{AFE}\times\log AQS_{2012}$						-0.0136 (0.0033)**
Constant	0.1007 (0.0135)**	-0.3608 (0.1894)	0.2355 (0.0410)**	0.0704 (0.0133)**	0.0707 (0.0618)	0.1899 (0.0321)**
Adj-R^2	0.262	0.079	0.470	0.434	0.326	0.784
Regression *F*	16.27	3.19	26.24	14.2	7.21	35.65
Obs.	87	78††	87	87	78††	87
Long-run convergence:	-0.0465 (0.0083)**	-0.0196 (0.0471)	-0.0669 (0.0106)**	-0.0281 (0.0082)**	-0.0646 (0.0384)	-0.0681 (0.0092)**

Notes: This table shows the estimated regression coefficients and standard errors are in parentheses. ** (*) = significant at 1% (5%). † Adding Age_{2012} is not statistically significant: t = -1.04 in (i); t = -1.57 in (iv); and t = 1.36 in (v). †† There are fewer observations for entrants due to 9 observations where *AQS* fell between 2012 and 2018, such that the log difference is undefined.

Results in columns (iv) to (vi) of Table 8 also suggest few statistically significant deviations from a uniform contribution to the convergence rate across universities and disciplines. For exits, *X*, there is some evidence of a larger convergence rate contribution for AUT (which initially had the lowest *AQS* and the fastest growth in the first period), and a slower rate for Lincoln (LU). For *T*, only Massey university (MU) displays a significantly greater rate of convergence. Across disciplines there is some evidence for different convergence rates on *E* or *T* for education, agriculture, and AFE.[26]

Overall, these results suggest that the largest components contributing towards β-convergence in *AQS* across universities and disciplines from 2012 to 2018 were via recruitment of entrants and by transforming the quality scores of established and remaining researchers. Exiting staff from those universities and disciplines also facilitated convergence of average qualify scores at the next PBRF audit, but made a smaller contribution: just under half of that of each of the other two components.

Nevertheless, an important aspect of these results is that entrants can be seen to contribute consistently towards β-convergence and display a mixed record of σ-convergence and σ-divergence. This latter result is captured by the change (arising from increases and decreases) in the variances for entrants across periods.

8. Conclusions

This paper has examined whether the NZ PBRFS has generated a greater concentration of research in a smaller number of higher-quality universities, or relatively greater improvements in initially lower quality universities, thereby facilitating a cross-university convergence process. A distinguishing feature of the analysis is the access to individual longitudinal data which enable an appropriate assessment of the processes determining convergence or otherwise. In particular, relative research quality changes are determined by the precise nature of staff turnover, in terms of exits and entrants, combined with quality transformations of incumbent staff.

A strong degree of β-convergence was found for the period 2012 to 2018. Despite the considerable initial variation across universities in their *AQS* scores, a common convergence process was found to operate across all universities, and all discipline groups within and across universities. Furthermore, the lag structure suggested that universities' growth in research quality from 2012 to 2018 was affected by growth in the prior period. This was such that a relatively high rate of improvement in the first period systematically mitigated growth in the second period. There was also some evidence that the *AQS* for one discipline, Accounting, Finance and Economics, may have converged at a slightly faster rate than other disciplines. It

[26] There are large values in Table 7 for the two Ag dummies for Entrants, suggesting a dramatic convergence effect and large autonomous *AQS* growth, D_{Ag}, over 2012 to 2018. However, there are few observations because AUT and LU Agriculture discipline groups units are omitted due to negative *AQS* changes.

was also found that the convergence properties were not affected by differences in gender ratios, median age, and size of universities, and their discipline composition.

Strong β-convergence is not necessarily associated with σ-convergence. However, the results confirm that a strong σ-convergence process is observed over 2003 to 2012. For universities, this was maintained during 2012 to 2018, despite the fact that the dispersion of *AQS* levels across universities and disciplines was already much reduced by 2012. For disciplines, σ-convergence was substantially reduced during 2012 to 2018, with σ-divergence in some cases.

A distinguishing feature of this analysis is the attention given to the contributing components of convergence. This analysis has been possible here due to the New Zealand PBRFS's design which required all qualifying academics to be assessed in all rounds and created a longitudinal database of individual assessments from successive PBRFS rounds.

When considering the contributions of researcher exits, entry and quality transformation, two outcomes were especially interesting. First, exits and quality transformations both contributed, as expected, to improvements in *AQS*s on average across universities and disciplines. New entrants (whether from outside the NZ system or cross-university transfers within it) raised *AQS* levels over the period 2003 to 2012, as they had an average quality in excess of the initial *AQS*, although their contribution to growth was less than that of incumbents. Over the period 2012 to 2018, entrants on average actually served to reduce *AQS* levels as their average quality was below the average in 2012. The combination of substantial quality improvement over the first period, combined with a difficulty of recruiting (and retaining) higher-quality researchers in the second period, contributed to significant 'decreasing returns' from the PBRFS.

Second, the overall decreasing returns combined with similar effects within universities and disciplines, such that all three components of change contributed to a process of β-convergence, rather than divergence, in *AQS* levels across universities and disciplines. The rate of *AQS* convergence was around –0.06, or 6 per cent, per year for entrants and transformations, and somewhat slower, at around –0.03 for exits.

Further, these convergence rates were relatively uniform across universities and disciplines with only a few exceptions. These exceptions are: a slower rate of convergence via exits for Lincoln university; a faster rate of convergence via exits for AUT; and a faster rate of convergence via quality transformations for MU. Among disciplines, the exceptions include: faster convergence via quality transformations for AFE, and via entrants to Agriculture; but a slower rate of convergence via quality transformation by Education.

In the New Zealand case, the PBRFS funding formula was not designed explicitly to favour increased concentration of researchers, nor to favour low-quality units. Rather, funding allocation was both scale-neutral and neutral with respect to the location of individuals with different quality scores. This level playing field in financial PBRF incentives across research units may have encouraged initially low-rated universities and disciplines to aim for substantial improvement over 2003 to 2018, and avoided discouraging a process of knowledge transfer across universities. These aspects may have facilitated the convergence outcome observed here.

Appendix A. Further details of the contributions of exits, entrants and quality transformations to changes in *AQS*s.

Table A1. Contributions of exits, entrants and quality transformations to changes in AQS: 2003 to 2012 and 2012 to 2018.

		AQS 2003	Exits	Entrants	Trans	*AQS* 2012	Exits	Entrants	Trans	*AQS* 2018
	All universities	2.88	1.57	-0.63	0.73	4.55	0.63	-0.96	0.69	4.91
University	AUT	0.77	2.00	-0.16	0.54	3.15	0.57	-0.86	0.87	3.73
	Lincoln	2.56	1.15	-0.67	0.47	3.51	1.29	-0.92	0.66	4.54
	Massey	2.10	1.76	-0.30	0.55	4.11	0.54	-0.65	0.56	4.56
	Auckland	3.67	1.40	-0.91	0.73	4.89	0.75	-1.01	0.75	5.38
	Canterbury	3.55	1.02	-0.62	0.65	4.61	0.69	-0.75	0.50	5.05
	Otago	3.18	1.60	-0.57	0.64	4.85	0.52	-1.10	0.59	4.86
	Waikato	2.98	0.87	-0.07	0.43	4.21	0.69	-0.53	0.58	4.95
	VUW	3.11	1.75	-0.42	0.93	5.38	0.32	-1.00	0.64	5.34
Discipline	Medicine	2.93	2.06	-1.24	0.74	4.49	0.70	-1.26	0.62	4.55
	Engineering	3.00	1.83	-0.77	0.51	4.57	0.70	-1.10	0.84	5.01
	Core science	3.79	1.91	-0.78	0.39	5.31	0.64	-1.18	0.51	5.28
	Management	2.21	1.35	-0.34	0.72	3.95	0.50	-0.55	0.61	4.51
	Acc Fin Eco	2.41	1.24	-0.08	0.39	3.96	0.40	-0.69	0.42	4.09
	Humanities	3.17	1.24	-0.43	0.76	4.74	0.65	-0.78	0.81	5.43
	Agriculture	3.65	1.75	-1.20	0.75	4.95	0.92	-1.35	0.93	5.45
	Law	3.04	1.46	-0.55	1.12	5.07	0.38	-0.61	0.66	5.5
	Education	1.38	1.61	-0.15	0.89	3.74	0.46	-0.62	0.44	4.02
AUT	Medicine	0.56	2.54	-0.46	0.53	3.17	0.71	-1.41	0.65	3.12
	Engineering	1.06	1.57	0.20	0.47	3.30	0.60	-0.88	0.98	4.00
	Core science	0.66	1.61	1.26	0.40	3.93	-0.56	0.53	0.29	4.19
	Management	0.87	2.25	-0.12	0.35	3.35	0.40	-0.63	0.79	3.91
	Acc Fin Eco	0.50	2.05	0.00	0.45	3.00	0.63	-0.54	0.79	3.88
	Humanities	0.85	2.22	-0.69	0.58	2.96	0.89	-0.91	1.21	4.15
	Agriculture	1.81	3.43	-2.26	0.76	3.74	0.72	-1.72	1.16	3.90
	Law	0.73	1.39	0.17	0.55	2.84	1.02	-0.12	0.81	4.55
	Education	0.57	1.40	0.13	0.45	2.55	0.44	-0.11	-0.06	2.82
Lincoln[a]	Medicine	2.15	2.13	-1.73	1.14	3.69	2.00	-0.54	0.2	5.35
	Engineering	2.40	1.69	-1.00	0.27	3.36	1.90	-1.45	0.74	4.55
	Core science	5.00	0.00	-1.00	0.00	4.00	2.00	1.33	0.00	7.33
	Management	1.86	0.08	-0.12	0.65	2.47	0.86	-0.15	0.52	3.70
	Acc Fin Eco	2.05	0.5	-0.18	-0.35	2.02	0.82	-0.14	0.51	3.21
	Humanities	2.66	0.89	-0.41	0.45	3.59	2.09	-1.20	0.32	4.80
	Agriculture	2.94	2.28	-1.56	0.58	4.24	1.55	-1.44	0.45	4.80
Massey	Medicine	2.15	2.06	-1.14	0.59	3.66	0.73	-0.87	0.53	4.05
	Engineering	1.51	2.84	-0.35	0.46	4.46	0.45	-0.78	0.50	4.63
	Core science	2.98	1.95	0.03	0.16	5.12	0.90	-0.71	0.35	5.66
	Management	1.58	0.91	0.58	0.39	3.46	0.20	0.05	0.22	3.93
	Acc Fin Eco	2.07	0.48	0.56	0.28	3.39	0.20	-0.26	0.75	4.08
	Humanities	2.37	1.62	-0.22	0.47	4.24	0.65	-0.75	0.71	4.85
	Agriculture	2.92	1.78	-0.99	0.79	4.50	0.78	-0.98	0.64	4.94
	Law	0.78	0.87	-0.04	0.13	1.74	0.39	-0.18	1.65	3.60
	Education	1.39	1.89	-0.17	0.72	3.83	1.01	-1.13	0.23	3.94
Auckland	Medicine	3.66	1.73	-1.65	0.90	4.64	1.04	-1.24	0.63	5.07
	Engineering	4.04	1.32	-0.95	0.68	5.09	0.78	-1.04	0.88	5.71
	Core science	4.16	1.55	-0.79	0.42	5.34	0.79	-1.33	0.60	5.40
	Management	3.09	1.11	0.01	0.28	4.49	0.27	-0.91	0.71	4.56
	Acc Fin Eco	3.39	1.28	0.01	0.33	5.01	0.02	-0.84	0.00	4.19
	Humanities	4.33	1.09	-0.57	0.44	5.29	0.40	-0.35	0.58	5.92
	Agriculture	4.81	0.75	-0.79	0.36	5.13	1.52	-1.23	0.98	6.40
	Law	3.65	1.11	-1.01	1.34	5.09	1.19	-0.76	0.41	5.93
	Education	1.61	1.58	-0.19	0.95	3.95	0.95	-0.67	0.53	4.76

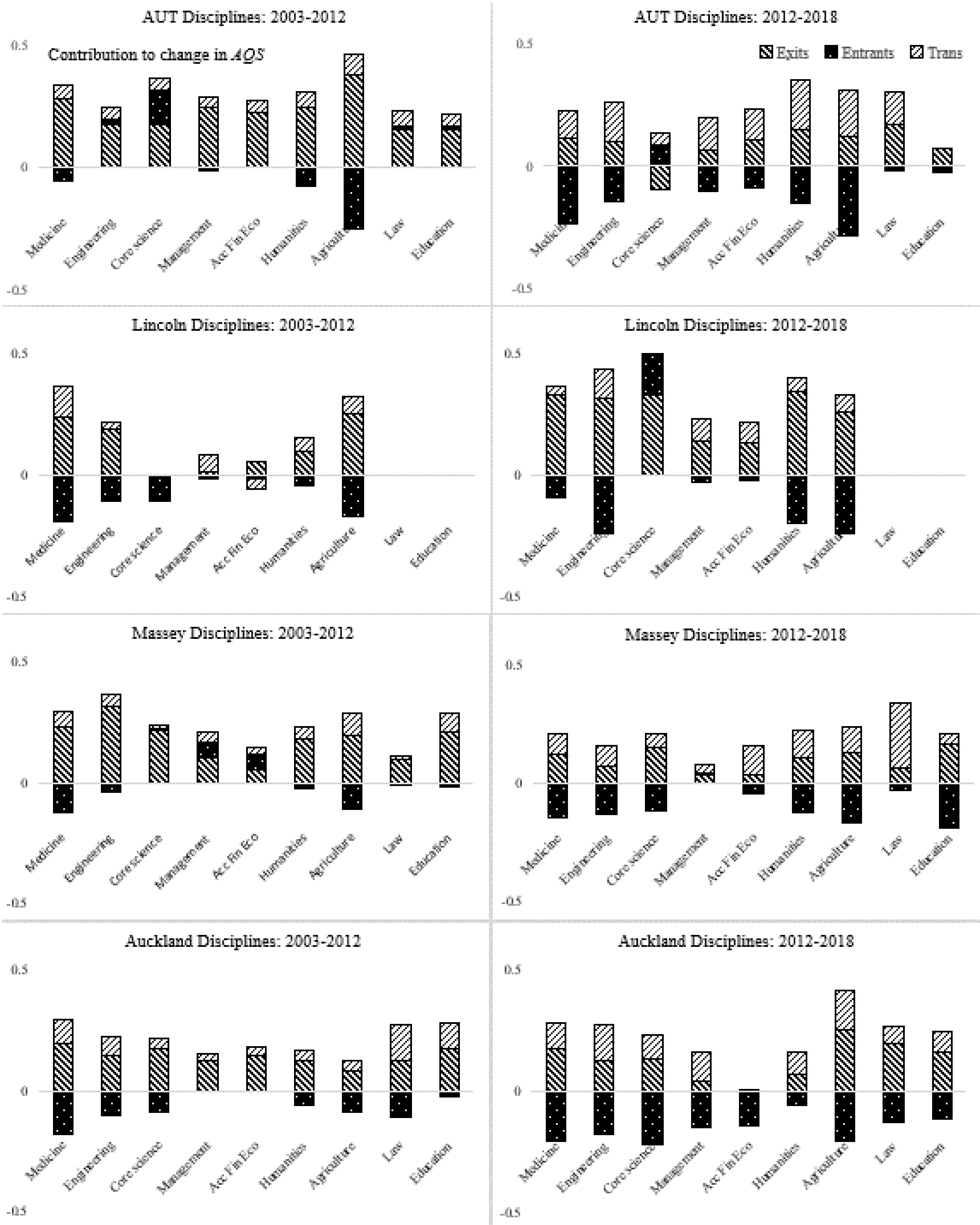
Canterbury	Medicine	4.23	1.25	-1.31	0.47	4.64	0.28	-0.75	0.56	4.73
	Engineering	4.64	1.34	-1.39	0.38	4.97	1.09	-1.58	0.70	5.18
	Core science	4.04	1.49	-1.02	0.38	4.89	1.05	-1.13	0.49	5.30
	Management	2.60	1.95	-0.79	0.91	4.67	0.25	-0.15	1.08	5.85
	Acc Fin Eco	2.46	0.91	0.51	0.49	4.37	-0.19	-0.20	0.26	4.24
	Humanities	3.45	0.90	-0.63	0.77	4.49	0.69	-0.31	0.43	5.30
	Agriculture	4.63	1.31	-0.80	0.17	5.31	1.08	-1.29	0.50	5.60
	Law	3.73	1.15	-0.18	0.80	5.50	0.52	-1.20	0.50	5.32
	Education	0.91	0.52	0.44	1.18	3.05	0.42	-0.20	0.20	3.47
Otago	Medicine	3.12	1.81	-0.87	0.69	4.75	0.50	-1.33	0.55	4.47
	Engineering	2.76	1.83	0.02	0.00	4.61	1.16	-0.73	1.02	6.06
	Core science	3.57	2.48	-0.98	0.55	5.62	1.01	-1.33	0.35	5.65
	Management	2.50	0.95	0.11	0.62	4.18	0.86	-0.55	0.97	5.46
	Acc Fin Eco	2.77	0.74	0.79	0.42	4.72	0.60	-1.28	0.58	4.62
	Humanities	3.48	1.16	-0.34	0.59	4.89	0.62	-0.69	0.57	5.39
	Agriculture	4.42	1.57	-1.19	0.64	5.44	0.75	-1.26	0.96	5.89
	Law	4.10	0.68	-0.45	1.95	6.28	-0.36	-0.38	-0.14	5.40
	Education	1.58	0.19	1.83	0.34	3.94	0.18	-0.64	0.42	3.90
Waikato	Medicine	3.48	0.76	-0.47	0.18	3.95	0.71	-0.39	0.54	4.81
	Engineering	4.26	0.72	-0.60	0.02	4.40	0.49	-0.58	0.44	4.75
	Core science	4.79	0.27	0.03	-0.56	4.53	0.26	-0.43	0.05	4.41
	Management	3.08	0.43	0.01	0.82	4.34	0.65	-0.39	0.40	5.00
	Acc Fin Eco	2.98	0.86	-0.19	0.26	3.91	1.17	-0.59	0.20	4.69
	Humanities	2.78	0.54	0.13	0.54	3.99	1.43	-0.51	0.79	5.70
	Agriculture	4.59	0.70	-0.88	0.71	5.12	1.17	-1.78	1.03	5.54
	Law	2.42	0.45	0.65	0.43	3.95	-0.12	-0.47	0.90	4.26
	Education	1.85	1.61	0.01	0.62	4.09	0.10	-0.48	0.50	4.21
VUW	Medicine	3.04	3.44	-1.28	0.82	6.02	0.92	-1.93	0.24	5.25
	Engineering	3.48	1.10	-0.45	0.55	4.68	0.21	-0.95	0.75	4.69
	Core science	4.08	2.34	-0.62	0.74	6.54	0.01	-1.62	0.07	5.00
	Management	2.94	1.42	-0.82	1.08	4.62	0.26	-0.29	0.04	4.63
	Acc Fin Eco	2.62	1.47	0.09	0.48	4.66	0.02	-0.81	-0.22	3.65
	Humanities	3.63	1.57	-0.03	0.55	5.72	0.44	-0.95	0.91	6.12
	Agriculture	3.74	2.77	-1.53	1.30	6.28	0.69	-2.02	1.27	6.22
	Law	3.05	2.23	-0.72	1.33	5.89	0.56	-0.60	0.67	6.52
	Education	0.91	1.89	-0.06	1.07	3.81	0.11	-0.04	0.32	4.20

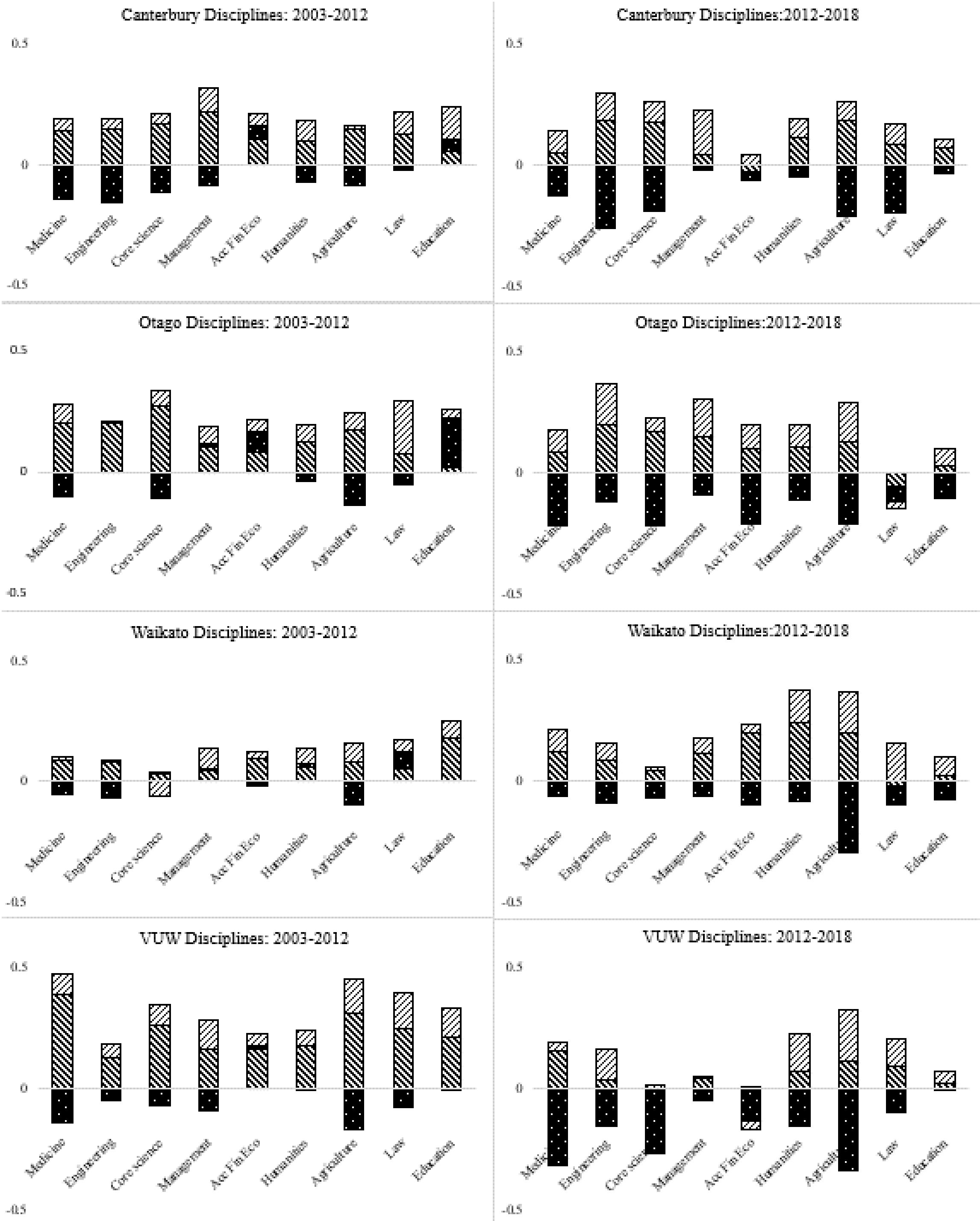
Notes: a: There were no observations for Lincoln University in the 2012 and 2018 assessment rounds for Law and Education discipline groups.

The component contributions to changes in the *AQS*s of disciplines within each university are shown in Figure A1. There is greater diversity in the contribution of exits, entrants and quality transformations at the level of disciplines within universities than there is amongst universities and disciplines shown in Figure 4. Although the dominant pattern of the impact of these researcher transitions is the same as for universities and disciplines as a whole, there are several cases where the impact of exits and quality transformations have a negative impact on *AQS*s, and of entrants having a positive impact.

Apart from Lincoln university, there is a declined in the size of the change in *AQS*s during the period 2012 to 2018 compared with 2003 to 2012. This pattern is associated with a general decline in the standard deviations of the size of the contributions of entrants and quality transformations, and an increase for exits. The changes are relatively large for disciplines within universities, especially those within AUT, Lincoln, Massey Otago and Waikato.

Figure A1. Contributions to exits, entrants and quality transformations to changes in AQS across disciplines.





Notes: Derived from Appendix Table A1.

Appendix B. Convergence: An illustration

This appendix illustrates how the various contributions to changes in AQSs can combine, given the observed characteristics of the component transitions, to produce a relationship displaying beta-convergence. A summary of the characteristics of exit and entry rates (which determined turnover and scale changes), along with net transformation rates, is given in Table B1. This indicates the different patterns, along with the way they depend on the initial quality score of the university, for high, medium and low-quality universities: for the detailed findings on which this table is based, see Buckle and Creedy (2019a) and Buckle *et al.* (2021).

Table B1. Rates of exit, entry and quality transformation

	High *AQS*	Medium *AQS*	Low *AQS*
Exit rates	Low As and Bs Low Rs	Some As and Bs High Rs	High Rs
Entry rates	High As High Bs Some Cs Low Rs	Some As High Bs Higher Cs Some Rs	Low As Few Bs Higher Cs Higher Rs
Net quality transformation	High upward movement	Some upward movement	Low net upward movement

To illustrate how these main characteristics lead to convergence, consider three hypothetical universities, having flow characteristics which correspond to those indicated in Table B1 as well as being representative of low-, medium- and high-quality universities in NZ. Table B2 shows flows based on actual flows for a selection of NZ universities, as reported by Buckle *et al.* (2021). The values are expressed as proportions of the initial number of FTEs in each Quality Category.[27] The final three columns of Table B2 show the flows of entrants, exits and net quality transformations. For example, the final column reflects the greater ability of the high-*AQS* university to transform researchers into As, as well to attract more As and Bs. The lower-quality universities manage to have higher exit rates for lower-quality researchers. Nevertheless the higher-quality university also makes a substantial number of new appointments at level C, tending to reduce its *AQS*, while at the same time having significant numbers of Cs who move to higher quality categories. The lowest-quality university recruits large numbers of C

[27] The absolute sizes are only relevant in affecting the influence of R-exits on the *AQS*. The university with the highest *AQS* is also assumed to be largest in terms of FTEs (of 1,540), while the lowest-quality university is the smallest in size (with initially 585 FTEs), while having the largest proportion of R-type researchers. The medium quality university is assumed to have 1,225 FTEs.

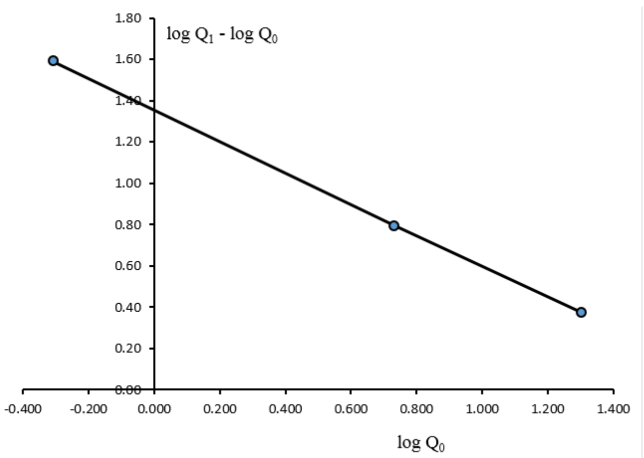
researchers, which in this case contribute to raising the *AQS*, while also achieving a high exit rate of R researchers.

Table B2. Three representative universities

QC	Initial FTE	Entrants	Exits	Net Transformations
AQS =3.68				
A	0.10	0.13	0.06	0.08
B	0.34	0.32	0.19	0.00
C	0.32	0.33	0.21	-0.05
R	0.24	0.02	0.19	-0.04
Total	1.00	0.80	0.66	
AQS = 2.08				
A	0.03	0.06	0.02	0.04
B	0.18	0.22	0.11	0.05
C	0.35	0.29	0.24	-0.03
R	0.44	0.02	0.37	-0.06
Total	1.00	0.58	0.75	
AQS = 0.73				
A	0.01	0.05	0.00	0.02
B	0.05	0.31	0.03	0.09
C	0.17	0.56	0.09	0.02
R	0.77	0.07	0.60	-0.12
Total	1.00	0.99	0.72	

Using the values in Table B2, it is possible to calculate the resulting new *AQS*s and, for each representative university, the log-change, log(Q_1) – log(Q_0). These are plotted against log(Q_0) in Figure B1, showing a negative linear relationship. This is the specification used to examine beta-convergence above.

Figure B1. Relationship between AQS log-change and initial log(AQS)



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