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Efficiency, technology and productivity change in Australian universities, 1998-2003

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Abstract:

In this study, productivity growth in thirty-five Australian universities is investigated using nonparametric frontier techniques over the period 1998 to 2003. The five inputs included in the analysis are full-time equivalent academic and non-academic staff, non-labour expenditure and undergraduate and postgraduate student load while the six outputs are undergraduate, postgraduate and PhD completions, national competitive and industry grants and publications. Using Malmquist indices, productivity growth is decomposed into technical efficiency and technological change. The results indicate that annual productivity growth averaged 3.3 percent across all universities, with a range from -1.8 percent to 13.0 percent, and was largely attributable to technological progress. However, separate analyses of research-only and teaching-only productivity indicate that most of this gain was attributable to improvements in research-only productivity associated with pure technical and some scale efficiency improvements. While teaching-only productivity also contributed, the largest source of gain in that instance was technological progress offset by a slight fall in technical efficiency.

JEL classification: C61; D24; I29; O30

Keywords: Productivity; technical and scale efficiency; technological progress; Malmquist indices; universities.

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1. Introduction

Over the last three decades the Australian university sector has moved progressively towards a greater appreciation of performance, very often at the instigation of the Commonwealth as the chief public funding body. In the late 1970s, the government first began to encourage universities to critically monitor their own performance. These efforts gained impetus in the 1980s when several major Commonwealth-funded discipline reviews set about determining standards with an aim to improve quality and efficiency in universities, largely in response to the large-scale structural reorganisation of the sector and the rapid growth in higher education participation.

By the early 1990s, the Commonwealth moved from discipline review to a whole-of-institution approach whereby individual universities were rewarded for improvements in various aspects of performance. At the same time, Australian universities were experiencing many not altogether unrelated trends in the sector which also served to heighten competition and the drive for better performance. These included: declining public funding per student, massive growth in international student numbers, increasingly competitive markets for international and domestic fee-paying students, rising expenditures on university infrastructure, heightened competition for research funding and academic expertise,

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development of international campuses and joint ventures, and increasing awareness of the interests of students, the community and other stakeholders.

These policy initiatives, combined with other market and non-market forces, have intensified since the late 1990s. Since 1998 all institutions have been required to submit to the Commonwealth an Institutional Quality Assurance and Improvement Plan detailing the university's goals and aims in the key areas of teaching and learning, research, management and community service and the performance indicators used to assess their success. A key goal is the public accountability of Australia's publicly-funded universities. Similarly, research funding has been increasingly tied to performance, comprising support for research training, general research and program-specific research. Despite the apparent dissimilarity of these channels, all are allocated, at least indirectly, on the basis of an institution's research performance, partially facilitated by the Commonwealth Department of Education, Science and Training's monitoring and assessment of research output. At the same time, the department disseminates detailed statistics on university financial performance as means of informing the sector's many stakeholders of its viability and ability to deliver good economic outcomes.

Undoubtedly, university reform *per se* and the anticipation of reform has affected the apparent productivity of the sector. In the period 1998-2003 alone, undergraduate, postgraduate and doctoral degree completions respectively grew by 23%, 56% and 45%, external government and industry grants by 19% and 29% and research publications by 30%, against a background where non-labour expenditure increased by 26% and academic and non-academic staff numbers increased a mere 5% and 10%, respectively. One suggestion is that the productivity of the sector has significantly improved through expansion of the productivity frontier, suggesting fewer (or the same) resources are now needed to produce the same (or more) economic outputs. Problematically, this may not be the case.

In a world without inefficiency, productivity growth, as measured by productivity indices (an index of output divided by an index of total input usage), is synonymous with technical progress (or shifts in the technology boundary). However, in a world in which inefficiency exists, productivity can no longer be interpreted as technical change unless there is either no technical inefficiency or unless technical inefficiency does not change over time. If these conditions do not hold, then productivity is redefined as the net effect of changes in efficiency (or movements relative to the existing frontier) and shifts in the production frontier (or technical change). This distinction is important from a policy viewpoint, since changes in productivity growth due to inefficiency suggest different policies to those concerning technical change. For example, in an industry characterised by a high level of inefficiency, efforts to promote innovation may be wasted, while a lack of innovation in an efficient industry may result in stagnation. In any case, remarkably little is known about the productivity of the Australian university sector, even less about the spread of productivity levels across the sector, and virtually nothing about whether suggestions of productivity improvements are the result of an increase in efficiency, an increase in technology, or both.

Accordingly, the purpose of this paper is to assess the recent productivity growth of Australian universities taking into account changes in both efficiency and technology. While not the only study to examine efficiency and/or productivity in Australian universities or university departments (Madden, Savage & Kemp, 1997; Abbott & Doucouliagos 2003a, 2003b; Carrington, Coelli, & Rao, 2005) it is the only one to focus exclusively on productivity, efficiency and technological change at a university-level using readily available panel data dated within the last five years. The paper is divided into four main sections. Section 2 focuses on the specification used to measure productivity, efficiency and technological change in Australian universities. Section 3 deals with the specification of inputs and outputs. Section 4 presents the results. The paper ends with some concluding remarks.

2. Malmquist indexes of productivity and technical change

The methodology employed to calculate productivity change and decompose it into its technical efficiency and technological component is the nonparametric Malmquist index [for pioneering works see Färe, Grosskopf, Lindgren, & Roos (1992) and Färe, Grosskopf, Norris, & Zhang (1994)]. The approach has since been applied to a number of service industries, including healthcare (Maniadakis & Thanassoulis, 2000; Ventura, Gonzalez, & Carcaba, 2004) and financial services (Worthington, 1999; Mahlberg & Url, 2003; Sturm & Williams, 2004). The only known education studies to use the Malmquist index approach are Flegg, Allen, Field, & Thurlow (2004) and Johnes, Johnes, Thanassoulis, Lenton, & Emrouznejad (2004) [see Worthington (2001) and Johnes (2006) for useful surveys of frontier efficiency measurement techniques in education].

The framework can be illustrated by Figure 1, following Coelli, Rao & Battese (1998). In this diagram, a production frontier representing the efficient level of output (*y*) that can be produced from a given level of input (*x*) is constructed, and the assumption made that this frontier can shift over time. The frontiers (*F*) thus obtained in the current (*t*) and future (*t*+1) time periods are labelled accordingly. When inefficiency is assumed to exist, the relative movement of any given university over time will therefore depend on both its position relative to the corresponding frontier (technical efficiency) and the position of the frontier itself (technical change). If inefficiency is ignored, then productivity growth over time will be unable to distinguish between improvements that derive from a university 'catching up' to the frontier, or those that result from the frontier itself shifting up over time.

<FIGURE 1 HERE>

Now, for any given university in period *t*, say, represented by the output/input bundle z_t, the inputs used are x_t and the output is y_t. But this is technically inefficient since the university lies below the production frontier: with the available technology and the same level of inputs the university should be able to produce output y_a. In the next period there is a technology increase such that more outputs can be produced for any given level of inputs: the frontier moves upward to F_{t+1}. Assume the university's output/input bundle is now represented by z_{t+1} with input x_{t+1} and output y_{t+1}. Once again the university is inefficient, but in reference to the new technology, and should be producing output y_c if it were efficient. The challenge for productivity assessment is to sort these increases in output relative to the level of inputs into that associated with the change in efficiency and that associated with the change in technology.

It is possible using the Malmquist output-orientated productivity index to decompose this total productivity change between the two periods into technological (or technical) change and technical efficiency change. Output-orientation refers to the emphasis on the equiproportionate augmentation of outputs, within the context of a given level of inputs. An output orientation is selected in this study since the outputs specified later are very much the focus of current governmental and university performance measurement and the inputs are somewhat less amenable to change, at least in the short run. Following Coelli, Rao & Battese (1998), the output-based Malmquist productivity change index may be formulated as:

$$M_O^{t+1}(y_t, x_t, y_{t+1}, x_{t+1}) = \left[\frac{D_O^t(y_{t+1}, x_{t+1})}{D_O^t(y_t, x_t)} \times \frac{D_O^{t+1}(y_{t+1}, x_{t+1})}{D_O^{t+1}(y_t, x_t)}\right]^{1/2} \qquad (1)$$

where the subscript O indicates an output-orientation, M is the productivity of the most recent production point (x_{t+1}, y_{t+1}) (using period t + 1 technology) relative to the earlier production point (x_t, y_t) (using period t technology), D are output distance functions, and all other variables are as previously defined. Values greater than unity indicate positive total factor productivity (TFP) growth between the two periods. An equivalent way of writing this index is:

$$M_O^{t+1}(y_t, x_t, y_{t+1}, x_{t+1}) = \frac{D_O^{t+1}(y_{t+1}, x_{t+1})}{D_O^t(y_t, x_t)}\left[\frac{D_O^t(y_{t+1}, x_{t+1})}{D_O^{t+1}(y_{t+1}, x_{t+1})} \times \frac{D_O^t(y_t, x_t)}{D_O^{t+1}(y_t, x_t)}\right]^{1/2} \qquad (2)$$

or $M = E \cdot P$ where M (Malmquist TFP) is the product of a measure of technical progress P as measured by shifts in the frontier measured at period t + 1 and period t (the geometric mean of the two ratios in the square bracket corresponding to y_c/y_b and y_b/y_a in Figure 1) and a change in efficiency E over the same period (the term outside the square bracket corresponding to $(y_{t+1}/y_c)/(y_t/y_a)$ in Figure 1). Using this approach, four efficiency/productivity indices are provided for each university along with a measure of technical progress over time. These are: (i) technical efficiency change (i.e. relative to a constant returns-to-scale technology); (ii) technological change; (iii) pure technical efficiency change (i.e. relative to a variable returns-to-scale technology); (iv) scale efficiency change; and (v) TFP change. Coelli, Rao & Battese (1998) discuss the linear programs necessary to calculate these indices and the DEAP 2.1 software used in this analysis.

3. Specification of inputs and outputs

The data consist of annual observations of thirty-five Australian universities over the period 1998 to 2003. This is longest and most recent period where consistent data on university inputs and outputs have been collected by the Commonwealth Department of Education, Science and Training (DEST). Three other Australian universities are excluded through the technical requirement for a balanced panel of data: the Australian National University (non-separable research funding associated with the Institute of Advanced Studies until 2000) and the Sunshine Coast and Notre Dame Australia universities (very small institutions only in operation since 2000). While the exclusion of the Australian National University from a sector wide comparison is commonplace owing to the uniqueness of its funding arrangements, as one of Australia's leading research universities its omission means the results must be qualified. The Australian Bureau of Statistics' consumer price index (education) is used to convert all monetary variables from nominal to real values (2000 = 100).

The inputs and outputs employed follow a production approach to modelling university behaviour, that is, universities combine labour and non-labour factors of production and produce outputs in the form of teaching, research, consultancy and other educational services. In terms of previous work, the approach selected is most consistent with Flegg, Allen, Field & Thurlow (2004), but also has a common conceptualisation of university performance as Beasley (1995), Johnes & Johnes (1993; 1995), Madden, Savage & Kemp (1997) and Athanassopoulos & Shale (1997). Six categories of output are employed. These are: (i) undergraduate completions, (ii) postgraduate completions and (iii) PhD completions; (iv) national competitive grants (in dollars) and (v) industry grants (in dollars); and (vi) publications (in points). Note that student completions include degrees and other undergraduate qualifications while publications include (points awarded in brackets) books (5 points), book chapters (excluding textbooks) (1 point), refereed journal articles (1 point) and refereed conference proceedings (1 point) [see DEST (2006) for the eligibility criteria].

Unmistakably, the numbers of undergraduate and postgraduate awards are an obvious measure of output for any university. Similarly, research is also an important output, signified by ongoing government research funding being currently distributed by a performance-based formula (weighting in brackets) comprising research income (60%), publications (10%) and doctoral students (30%). Correlation between the research outputs is also high, with correlation coefficients of no less than 0.93 between grants and research publications. Clearly, there are also interrelationships between the research and teaching dimensions of university performance. For instance, the number of doctorates awarded also influences the research funding received.

Nevertheless, there are three obvious limitations with the selected output specification. First, it is well known that using research income as a proxy for output is problematic (and a cause of great consternation to economists), though understandable (Flegg and Allen, 2007). However, it could be argued that the dollar value of research income may also reflect the market value of university research output. Second, there is no direct allowance for quality. But putting aside the lack of alternative measures, this is entirely consistent with current government policy. For example, Commonwealth funding for students by discipline is identical across universities, a dollar of research income is treated the same regardless of its source, and among the publications recognised as research outputs, there is no attempt to distinguish between high and low-quality outcomes. Finally, there is no recognition of the non-teaching and non-research outputs that universities can provide. These include informed commentary by academics in the media and at public forums and inquiries, recreational services like sporting activities and cultural events, additional services for indigenous, rural, disabled and other disadvantaged students, and engagement with business and community groups. In the absence of any specific measurement, this analysis assumes such ‘unmeasured’ outputs increase in proportion to the measured outputs.

The inputs included in the analysis are full-time equivalent (i) academic staff, (ii) non-academic staff, (iii) non-labour expenditure (including academic activities and research, libraries, other academic support services, student services, public services, buildings and grounds and administration and other general institution services), (iv) undergraduate student load, and (v) postgraduate student load (both in effective full-time students units or EFTSU). The input specification is comparable to a study of British universities by Flegg, Allen, Field, & Thurlow (2004). Unfortunately, the data do not allow the separation of academic staff into teaching and research or research-only staff, nor is it possible to separate non-academic staff into teaching or research-related support services.

<TABLE 1 HERE>

Table 1 presents a summary of descriptive statistics for outputs and inputs across the thirty-seven universities by year. Sample means, maximums, minimums, standard deviations and skewness and kurtosis are reported. As shown, in 2003 the typical Australian university awarded degrees to 3,846 undergraduates and 2,001 postgraduates and granted 132 doctorates. At the same time, national competitive grants summed to $14,650,000, industry grants to $10,553,000 and DEST-recognised research output to 931 points. On average, these outputs were achieved with 860 academic staff and 1,171 non-academic staff, $11,622,000 in non-labour expenditure and student loads of 11,509 undergraduates and 3,481 postgraduates. As a means of highlighting changes over the sample period, geometric mean growth rates for all outputs and inputs were calculated and are presented in Table 2. The averages of all outputs and inputs for each university are included in the last two columns.

<TABLE 2 HERE>

A point to note is that the variables used as inputs and outputs in Tables 1 and 2 are clearly not normally distributed. That said, the nonparametric, nonstochastic methodology employed in this study does not rely upon conventional asymptotic distributional assumptions, and it is only in the case of the most extreme outliers that a decision-making unit (i.e. a university) would be excluded. As an example, in their study of forty-five equally diverse British universities, Flegg, Allen, Field, & Thurlow (2004) excluded only the London and Manchester business schools, and then only because these had no undergraduate students at all. In general, the nonparametric nature of this type of analysis is always problematic, but work by Simar and Wilson (1998) to produce bootstrap confidence intervals of measures of efficiency is one way in which it may be resolved. Johnes, Johnes, Thanassoulis, Lenton & Emrouznejad (2004) also include robustness tests for outliers that could potentially be useful.

4. Empirical results

Table 3 presents the geometric mean changes in efficiency, technology and productivity growth by year and university (all figures to one decimal place only). Using this information, three primary issues are addressed in the computation of Malmquist indices of productivity growth over the sample period. The first is the measurement of productivity growth over the period. The second is to decompose changes in productivity growth into what are generally referred to as a ‘catching-up’ effect (technical efficiency change) and a ‘frontier shift’ effect (technological change). The third is that the ‘catching-up’ effect is further decomposed to identify the main source of improvement, through either enhancements in pure technical efficiency or increases in scale efficiency.

<TABLE 3 HERE>

Three points should be emphasised concerning the efficiency, technology and productivity growth indexes before proceeding. First, the indexes (and any resulting percentage changes) are relative. Put differently, a university may be more or less efficient, or more or less productive, but only in reference to the other thirty-four universities. At the same, productivity growth is also a relative concept: a larger university may be more productive (producing more outputs), but its productivity growth may still be low (when related to inputs). Second, the technique employed places no emphasis on particular inputs and outputs. On one level, this means that if a university chooses to focus, say, on teaching rather than research outputs, or postgraduate as against undergraduate education, its efficiency is only assessed relative to best-practice universities making similar sorts of decisions.

As shown in column 6 in the last row of Table 3, there was an annual mean growth in TFP of 3.3 percent for the period 1998 to 2003 across the university sector. Given that productivity growth is the sum of technical efficiency and technological change, the major cause of productivity growth can be ascertained by comparing the values of the efficiency change and technological change. Put differently, the productivity growth can be the result of efficiency gains, technological improvements, or both. In the case of universities, the overall improvement in productivity over the period is composed of an average efficiency increase (movement towards the frontier) of 0.0 percent, and average technological progress (upward shift of the frontier) of 3.3 percent annually. The technical efficiency can be further decomposed into pure technical efficiency and scale efficiency and this indicates a -0.1 percent fall in the case of the former and a 0.1 percent improvement in the latter. Clearly, across all Australian universities, the improvement in productivity over the period 1998-2003 is the result of an expansion in the frontier relating inputs to outputs rather than any improvements in efficiency. One suggestion is that in relative terms, the university sector is relatively efficient and that technological improvements have been well spread across the sector.

The figures also compare well with other sectors in the Australian economy. Cobbold & Kulys (2003), for example, identified the high multifactor productivity growth industries over the period 1974/95-2001/02 as agriculture, forestry and fishing (3.1%), manufacturing (2.8%), mining (3.0%), wholesale trade (2.1%) and transport and storage (3.3%). The productivity growth also appears comparable to the study by Flegg, Allen, Field & Thurlow (2004) of British universities over the earlier period 1980/81 to 1992/93, which suggested an arithmetic mean growth rate of 3.6 percent.

However, these figures obscure very different results across a number of universities which are ranked by their TFP growth in the final column. Central Queensland, for example, had a mean productivity growth of 13.0 percent (first-ranked) which was composed of a 2.6 percent improvement in efficiency (moving towards the efficient frontier) and a 10.1 percent technological gain (movement in the frontier). In turn, almost all of the technical efficiency gain was due to the improvement in pure technical efficiency (2.5 percent) with a negligible contribution through scale efficiency (0.1 percent). By way of comparison, Tasmania was ranked second in terms of productivity growth (7.9 percent): comprising a 6.5 percent technological gain and a 1.4 percent improvement in scale efficiency. Lastly, Ballarat was third-ranked with productivity growth of 7.7 percent, entirely attributable to technological progress. This seems to correspond with what is known about firm-level productivity growth: impressive rates of growth can occur from a low base as universities eliminate inefficiency, but productivity growth is more difficult to sustain as inefficiency is removed and reliance placed on technological improvements.

At the other end of the scale are universities with a low rate of TFP growth over the period. For example, productivity fell on average by 1.8 percent each year at Canberra, 1.4 percent at Australian Catholic, 1.3 percent at New England and 1.2 percent at Technology, Sydney. In most instances, the decline in productivity was not the result of greater inefficiency, but a contraction in their best-practice frontier. At Canberra, undergraduate load and national competitive and grants fell on average by 6.9, 11.7 and 3.2 percent, respectively; at Australian Catholic undergraduate and postgraduate completions fell by -0.4 and -2.1 percent and inputs increased massively by 30.1 percent. This extreme fall in technical efficiency may reflect ‘congestion’, whereby an increase in inputs is accompanied by a decrease in outputs. Unfortunately, this cannot be addressed with the methodology used in this study. At New England, contractions in postgraduate completions (-4.2 percent), national competitive grants (-0.9 percent) and publications (-11.0 percent) were accompanied by a reduction in full-time non-academic staff (-1.4 percent) and postgraduate load (-3.0 percent). New England (in Armidale), one of Australia’s oldest and most-respected universities, has struggled in the post-Dawkins reform period with the conversion of capital city colleges of advanced education and institutes of technology (comparable to polytechnics) to full university status.

Further insights are gained by examining the changes in pure technical and scale efficiency (where technical efficiency = scale efficiency × pure technical efficiency). Consider pure technical efficiency. Some universities have clearly improved by moving towards their best practice frontier – increasing outputs relative to inputs subject to the available technology – and this helped improve TFP growth. Two institutions that improved their productivity growth through efforts to remove inefficiency include Central Queensland (2.5 percent) and Southern Cross (1.8 percent). Some suggestion of this was gained through the analysis of input and output growth rates in Table 2 with Central Queensland outputs increasing by 9.2 percent and Southern Cross's by a more modest 3.3 percent, while limiting growth in inputs to 8.7 percent. These findings are not difficult to justify. For example, Central Queensland (a newer regional university based in Rockhampton) pursued an aggressive policy of opening branch campuses in capital cities during the sample period, and this dramatically increased both domestic and international student numbers. However, since these campuses used existing permanent academic staff teaching through distance education or off-load or casual staff, labour inputs did not rise as fast. Accusations were also made in the media that these campuses were less well-resourced, especially in terms of library facilities and student services.

On the other hand, the Queensland University of Technology's pure technical efficiency worsened on average by 2.5 percent each year from 1998 to 2003, which was partly offset by a 0.6 percent annual improvement in scale efficiency. Put differently, with the same level of inputs, the Queensland University of Technology should have been able to produce 2.5 percent more outputs but by increasing the scale of its operations, it had managed to increase outputs by 0.6 percent. In sum, the Queensland University of Technology is one of Australia's largest universities, and during this period it directed a sizeable amount of resources into the physical development of its three main campuses (Gardens Point, Kelvin Grove and Carseldine) and a fourth campus at Caboolture. As a traditionally undergraduate teaching institution it also tried, but with only limited success, to lift its research profile through the redirection of resources from teaching to research and coursework to research training.

Other universities whose productivity growth benefited from improvements in scale efficiency include Griffith (1.7 percent), Western Sydney (1.7 percent) and Murdoch (1.5 percent). This also appears consistent with developments in these institutions. For example, Western Sydney was formed through the amalgamation of three fiercely independent institutions, and during this period, intense effort was directed at combining these campuses so as to exploit the posited scale economies. Likewise, Griffith principally comprises an older campus with low-growth prospects (Nathan) in a highly competitive market (Brisbane) and a newer, fast-growing campus on the Gold Coast. During this period, the university was actively engaged in reallocating resources to the Gold Coast and rationalising schools and other overlap across the two campuses.

As a test of robustness, two supplementary analyses were undertaken. In the first analysis, the Australian National University (ANU) was added to the thirty-five universities specified earlier. As a consequence, the sample period is necessarily restricted to the sub-period 2000/01–2002/03 when comparable research funding information was available for the ANU. Despite the changes in the sample of universities and the sampling period, the results in Table 4 and the earlier results in Table 3 are fairly consistent, with the slightly higher mean productivity growth rate of 4.9 percent, still arising primarily from technological change. Universities with the highest productivity growth rates during this sub-period (ranking for the total period in brackets) are Royal Melbourne Institute of Technology (6^{th} ranked), Central Queensland University (1^{st} ranked) and the University of Tasmania (2^{nd} ranked). The ANU is ranked fourth in terms of productivity growth. The rank correlation coefficient between the productivity growth rates for each university in the model with ANU and those from the model without ANU is 0.844 (p-value = 0.000).

<TABLE 4 HERE>

In the second analysis, the full sample period was again specified (requiring the removal of the ANU), but the number of individual inputs and outputs are reduced through aggregation. This reflects a concern that, with only thirty-five decision-making units, the six inputs and five outputs specified may mean the analysis lacks discriminatory power. Two new inputs were calculated comprising total full-time equivalent staff (both academic and non-academic) and total student load (both undergraduate and postgraduate) and specified along with non-labour expenditure as defined earlier. In terms of outputs, undergraduate, postgraduate and PhD completions are summed to give total student completions, national competitive and industry and other grants are summed to give total grants; these were then included with publications as defined earlier. The results using this set of three inputs and three outputs are provided in Table 5. As shown, mean productivity growth is noticeably higher at 4.3 percent across the sector with almost all of the gain still from technological change. The rank correlation coefficient between the productivity growth rates for each university in this three-input, three-output model and those from the six-input, five-output model specified earlier is 0.851 (p-value = 0.000).

<TABLE 5 HERE>

In order to understand the sources of these changes in productivity growth, two additional specifications of university productivity growth are examined. The first of these focuses on ‘research-only’ productivity growth and the second on ‘teaching-only’ productivity growth. Variable definitions in both instances are identical to the earlier analysis, except that for the research-only specification, undergraduate and postgraduate completions are removed as outputs along with undergraduate and postgraduate student load as inputs, whereas in the teaching-only specification outputs comprise only undergraduate and postgraduate completions. Ideally, it would be better if the other inputs of academic and non-academic staff and non-labour expenditure could have been split along the lines of research-related and teaching-related, but this was not possible.

The geometric means for the efficiency, technology and productivity growth percentage changes for both approaches are presented in Table 6. The reduction in the number of outputs, from five to three for research and five to two for teaching, is normally associated with an increase in inefficiency because of the reduction in the number of best-practice institutions defining the frontier. This appears to be the case. In terms of research-only productivity growth, the best-ranked performers are Charles Sturt (25.1 percent), South Australia (19.2 percent), Royal Melbourne (17.9 percent), Murdoch (16.2 percent) and Queensland University of Technology (14.0 percent) while research productivity growth across the sector averaged 6.3 percent. When weighted by the share of sector output for each university, the sector averaged just 4.0 percent, indicating that much of the productivity growth was in universities with low research output. Inefficiency averaged 4.8 percent per year, with 2.8 percent of this due to growth in pure technical inefficiency and 1.9 percent due to growth in in scale inefficiency. Just 1.4 percent of the productivity growth occurred via technological improvements. On the other hand, for teaching only productivity growth the best ranked universities were Central Queensland (13.7 percent), La Trobe (9.3 percent), Tasmania (8.9 percent), Ballarat (8.9 percent) and Western Australia 8.4 percent) with a sector average of 2.9 percent. However, unlike research-only output, when teaching productivity growth was weighted by each university’s share of teaching outputs, the sector averaged 3.2 percent growth. This suggests that most productivity growth was concentrated in universities with high teaching outputs.

<TABLE 6 HERE>

While care must be taken in the interpretation of these results owing to the overlap in teaching and research-related inputs, it is clear that much of the overall productivity growth improvement in universities over this period was associated with gains in research productivity. Of this, most can be accounted for by universities catching up to the frontier through pure technical efficiency improvements rather than the frontier expanding over time. By way of contrast, improvements in teaching productivity have been more modest and largely linked with technological improvements, but this has been offset by a decrease in teaching efficiency. These insights can also be referenced to individual universities. Consider Central Queensland, which was highest ranked in overall TFP growth. While Central Queensland recorded relatively high growth in research-only productivity (6.8 percent, ranked 13th), it was largely through improvement in teaching-only productivity growth (13.7 percent, 1st ranked) that it performed well overall. A similar situation holds for second-ranked Tasmania (25th ranked in research and 3rd ranked in teaching), third-ranked Ballarat (17th ranked in research and 3rd ranked in teaching) but not for fourth-ranked Western Sydney (6th ranked in research and 9th ranked in teaching).

5. Concluding remarks

This study has examined the productivity growth of Australian universities over the period 1998-2003. The inputs included in the analysis were full-time equivalent academic and non-academic staff, non-labour expenditure and undergraduate and postgraduate student load and the outputs were undergraduate, postgraduate and PhD completions, national competitive and industry grants and publications. Using Malmquist indices, productivity growth was decomposed into technical efficiency and technological change. The results indicate that annual productivity growth averaged 3.3 percent across all universities, with a range between -1.8 percent and 13.0 percent, and was largely attributable to technological progress. Gains in scale efficiency appear to have played only a minor role in productivity growth. Two supplementary analyses, one including the Australian National University over a recent sub-period and another with a small number of individual inputs and outputs, reveals the results to be remarkably robust, with comparable productivity growth, sources of productivity growth and rankings of universities.

However, separate analyses of research-only and teaching-only productivity growth indicated that annual productivity growth in research and teaching averaged 6.3 percent and 2.9 percent respectively, suggesting most productivity growth was associated with improvements in research rather than teaching. In turn, the increase in research productivity growth was mostly associated with the removal of inefficiency rather than technological improvement, whereas the teaching gains were mainly sourced from technological gains with very little efficiency improvement. It is clear to see that some of gains made by universities in the provision of electronic library services and learning materials, online student management systems, the provision of distance, online and multi-campus delivery, cross-campus, student exchange and out-of-semester enrolments, etc. have greatly benefited teaching productivity growth. These are primarily capital-based improvements and this is reinforced by the low rates of growth in (especially) academic and (less so in) non-academic staff, and the much higher growth rates in non-labour expenditure over the period. The fact that there is very little technical inefficiency may also indicate that most universities are operating near the best-practice frontier suggesting the widespread diffusion of management and teaching practices aimed at improving outputs [though it could also be the result of the relatively large number of inputs and outputs specified].

The decomposition of research-only productivity growth is also unsurprising. Certainly there have been avenues for improving research productivity growth, as newer universities have developed research cultures based on practices well established in the older larger universities, both in Australia and elsewhere. The promotion and rewarding of highly-performing researchers, investment in offices of research aimed at increasing the number of grant applications and publications, the proliferation of refereed conference and journal venues, and the generally positive emphasis placed on research in all universities, faculties, schools and departments have assisted these developments. But most of these changes have merely brought underperforming universities up to the best-practice frontier, which itself has changed relatively little. As a labour-intensive activity, this is to be expected, and it is difficult to see the prospect for sustained productivity growth improvements in a function that has changed little over many decades.

As a rule, the largest productivity growth improvements have been found in smaller, newer universities rather than in the larger, older universities. This suggests that these universities may be in a better position to undertake some of the primary sources of productivity growth. These include improvements in production processes, the better integration of these processes, an increase in the scale of production, an attempt at improving the quality of inputs, and changing the scope of operations. As these institutions mature, at least some of these will be exhausted and productivity growth will start to slow, but is also likely that that some of these sources of productivity growth that take longer to change, such as the quality of (academic staff) inputs, will then start to yield longer-run benefits. But it also appears that productivity growth across the sector has slowed in overall and teaching only-terms and, given the overall higher efficiency, further gains will rely on technical innovation. This remains a challenge to the sector.

In terms of future research, a key limitation of this analysis is that no direct allowance has been given to the quality of inputs and outputs. For example, it is possible that the high productivity growth rates achieved by some universities in Australia through higher student completions have only been achieved by sacrificing graduate quality. From a different perspective, it is unlikely that the academic inputs and research outputs across the sector are consistently of the same quality. Clearly, the current emphasis of the Commonwealth government on a research quality framework [similarly to past developments in the UK] is a step in this direction, and may ultimately yield new information that will assist future researchers by enabling them to include both quantity and quality dimensions in their analyses.

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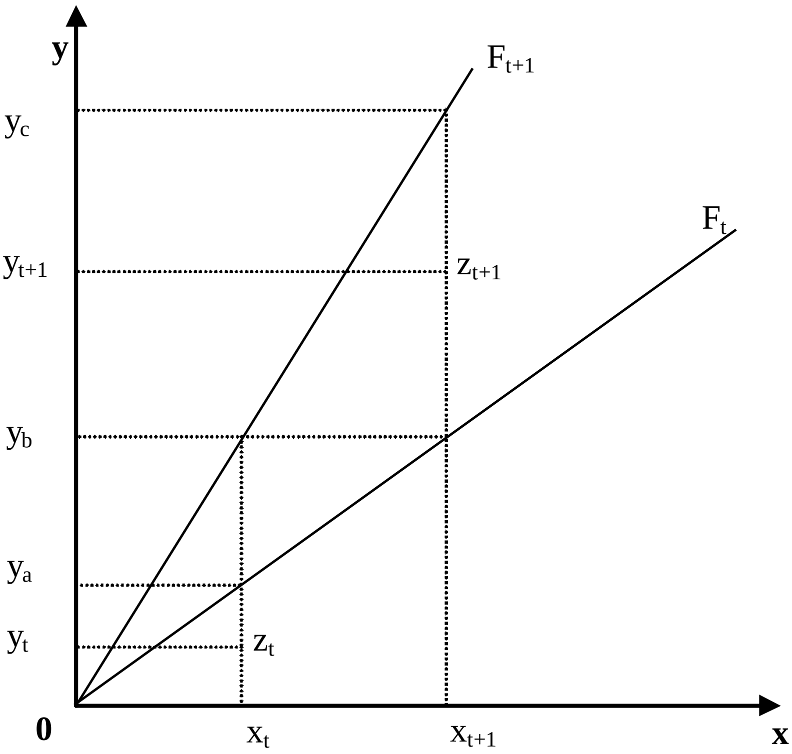

Fig. 1. Efficiency, technology and productivity change

Table 1
Selected descriptive statistics of university outputs and inputs by year, 1998-2003

Year	Statistic	Undergraduate completions (n)	Postgraduate completions (n)	PhD completions (n)	National competitive grants $('000)	Industry and other grants $('000)	Publications (weighted)	Full-time equivalent academic staff (n)	Full-time equivalent non-academic staff (n)	Non-labour input expenditure $('000)	Actual undergraduate student load (EFTSU)	Actual postgraduate student load (EFTSU)
1988	Mean	3130	1284	91	12324	8149	722	817	1061	92501	12210	2240
	Std. deviation	1597	748	95	16649	10902	687	551	675	66821	6131	1351
	Minimum	568	253	3	210	15	66	183	218	18680	2102	393
	Maximum	7075	2898	330	57882	38154	2595	2188	2714	272168	26433	5309
	Skewness	0.470	0.430	1.454	1.655	1.967	1.573	1.429	1.190	1.423	0.542	0.853
	Kurtosis	-0.520	-0.775	1.061	1.463	2.867	1.717	1.315	0.786	1.292	-0.550	-0.088
1999	Mean	3164	1312	98	12838	8242	747	807	1064	94966	12431	2432
	Std. deviation	1599	772	100	17109	10580	701	540	666	67956	6249	1518
	Minimum	590	301	4	279	139	91	169	217	19041	2204	418
	Maximum	6508	3054	342	61771	39580	2791	2122	2717	251403	26657	6085
	Skewness	0.478	0.660	1.527	1.720	1.902	1.548	1.373	1.189	1.258	0.540	0.999
	Kurtosis	-0.767	-0.300	1.343	1.739	2.920	1.663	1.136	0.792	0.679	-0.561	0.262
2000	Mean	3221	1445	103	12946	9016	712	810	1066	97212	12638	2575
	Std. deviation	1689	914	105	17248	11681	656	542	660	69969	6427	1553
	Minimum	515	270	5	160	498	69	159	200	17972	2245	450
	Maximum	6649	3354	399	60519	41043	2331	2137	2676	269322	27621	6141
	Skewness	0.468	0.712	1.669	1.681	1.904	1.484	1.370	1.147	1.331	0.540	0.855
	Kurtosis	-0.870	-0.426	2.091	1.509	2.579	1.167	1.173	0.706	0.931	-0.536	-0.040
2001	Mean	3462	1613	105	12817	10153	733	820	1086	102710	13184	2849
	Std. deviation	1926	1001	102	17001	13914	662	554	666	71813	6706	1689
	Minimum	482	272	5	482	405	93	159	175	16124	2160	562
	Maximum	9205	3870	388	63468	51083	2351	2173	2738	274238	28336	6845
	Skewness	0.894	0.765	1.646	1.702	2.002	1.467	1.381	1.146	1.243	0.499	0.868
	Kurtosis	0.733	-0.244	1.886	1.735	2.979	1.033	1.157	0.758	0.718	-0.634	0.140
2002	Mean	3659	1797	119	12859	10541	843	837	1127	115509	11523	3196
	Std. deviation	1986	1020	116	17719	15507	754	565	700	86023	5572	1932
	Minimum	532	326	4	539	369	93	165	192	29403	2252	662
	Maximum	9128	4493	459	68187	62654	2855	2269	2781	339492	23849	7677
	Skewness	0.807	0.775	1.696	1.819	2.224	1.566	1.392	1.140	1.489	0.497	0.906
	Kurtosis	0.171	0.174	2.093	2.336	4.297	1.454	1.262	0.612	1.474	-0.593	0.171
22003	Mean	3846	2001	132	14650	10533	931	860	1171	116220	11509	3481
	Std. deviation	2102	1183	124	20255	15738	800	592	732	82522	5526	2110
	Minimum	563	373	10	510	297	107	155	160	27833	2217	600
	Maximum	9430	4861	491	75210	65080	2858	2423	2883	355936	24143	8450
	Skewness	0.691	0.672	1.717	1.787	2.259	1.490	1.471	1.132	1.437	0.524	0.859
	Kurtosis	0.008	-0.044	2.443	2.091	4.558	1.215	1.532	0.629	1.505	-0.493	-0.007

Sources and notes: (i) Full-time equivalent academic and non-academic staff: DEST, Higher Education Statistics Collections (Various Issues), Canberra (www.dest.gov.au - accessed 30 May 2005); (ii) expenditure on non-labour inputs: DEST, Finance - Selected Higher Education Statistics (Various Issues), Canberra (www.dest.gov.au - accessed 30 May 2005), non-labour inputs consist of non-labour academic and research expenditure (equipment, travel, consumables, etc.), libraries, other academic support services, student services, public services, buildings and grounds and administration and other general institution services; (iii) actual student load (EFTSU) all undergraduate and postgraduate students: DEST, Higher Education Statistics Collections (Various Issues), Canberra (www.dest.gov.au - accessed 2 June 2005); (iv) undergraduate, postgraduate and PhD completions: DEST, Students - Selected Higher Education Statistics (Various Issues), Canberra (www.dest.gov.au - accessed 30 May 2005), postgraduate completions consist of Master's by research, by coursework and other postgraduates - excludes PhD completions. A PhD completion includes both research and coursework components; (v) for national competitive grants and industry grants: DEST, Higher Education Research Data Collection time series data 1992-2003 (via www.avcc.edu.au - accessed 31 May 2005); (vi) weighted publications: AVCC, Higher Education Research Data Collection time series data 1992-2003 (www.avcc.edu.au - accessed 31 May 2005).

Table 2
Geometric mean growth rates in university outputs and inputs, 1998-2003

Institution	Undergraduate completions (n)	Postgraduate completions (n)	PhD completions (n)	National competitive grants $('000)	Industry and other grants $('000)	Publications (weighted)	All outputs	Full-time equivalent academic staff (n)	Full-time equivalent non-academic staff (n)	Non-labour input expenditure $('000)	Actual undergraduate student load (EFTSU)	Actual postgraduate student load (EFTSU)	All inputs
Australian Catholic University	-0.42	-2.07	10.76	19.43	139.10	13.69	30.08	1.40	4.56	3.04	-0.21	1.51	2.06
Central Queensland University	16.78	23.66	20.11	2.75	12.48	8.41	14.03	1.41	7.62	14.21	-0.06	22.88	9.21
Charles Sturt University	7.33	11.29	22.87	17.52	-23.42	24.11	9.95	-0.26	1.52	0.87	3.94	11.28	3.47
Curtin University of Technology	6.53	12.61	18.02	2.43	5.98	2.24	7.97	2.17	4.43	3.96	-4.07	8.96	3.09
Deakin University	1.09	7.90	12.20	16.17	23.40	12.33	12.18	2.62	0.91	6.28	-3.53	8.67	2.99
Edith Cowan University	4.33	10.00	20.71	2.64	8.38	8.71	9.13	-1.34	0.23	2.46	0.42	8.88	2.13
Flinders University of South Australia	0.49	18.72	-0.24	-7.69	5.28	-1.54	2.50	-2.10	1.79	-2.75	0.72	9.17	1.36
Griffith University	3.86	12.97	8.79	3.92	6.30	9.11	7.49	2.64	4.32	4.16	0.77	13.71	5.12
James Cook University	6.61	8.98	1.67	-4.61	13.96	8.05	5.78	0.36	6.87	7.73	3.35	4.07	4.47
La Trobe University	0.92	11.40	5.64	-4.22	5.32	0.05	3.18	-0.84	3.62	6.26	-0.01	10.14	3.83
Macquarie University	5.95	12.96	-0.60	-9.39	6.90	4.29	3.35	1.19	-1.90	9.71	-0.98	10.49	3.70
Monash University	5.91	10.68	5.88	2.89	14.34	6.01	7.62	2.50	3.36	4.31	-4.32	12.19	3.61
Murdoch University	3.15	8.85	4.56	9.34	11.09	3.62	6.77	1.33	1.46	7.12	-1.22	2.76	2.29
Northern Territory University	-0.18	8.07	16.12	8.28	8.81	3.53	7.44	-5.80	-6.00	10.82	1.07	2.98	0.61
Queensland University of Technology	3.50	1.40	2.47	2.04	12.84	9.22	5.25	-0.04	0.93	6.30	0.03	3.59	2.16
Royal Melbourne Institute of Technology	0.89	4.00	14.04	0.78	0.24	16.41	6.06	0.92	4.71	6.82	-5.93	8.07	2.92
Southern Cross University	9.31	5.04	28.67	5.27	-10.03	14.14	8.73	-1.19	1.51	3.51	0.72	11.96	3.30
Swinburne University of Technology	4.49	6.02	12.20	19.30	-9.23	18.06	8.47	3.80	0.22	12.62	-3.96	12.22	4.98
University of Adelaide	3.76	18.08	6.41	5.77	4.83	2.47	6.89	0.51	-0.91	1.67	-0.43	5.47	1.26
University of Ballarat	-2.84	12.87	41.47	21.90	14.21	22.69	18.38	-1.00	4.58	8.93	-1.01	26.44	7.59
University of Canberra	4.18	7.26	21.67	-6.90	-11.74	0.46	2.49	2.28	2.59	3.56	-3.22	9.53	2.95
University of Melbourne	6.26	9.01	10.14	5.38	15.64	1.95	8.06	1.54	1.70	7.55	-2.87	7.98	3.18
University of New England	2.51	-4.16	3.05	-0.95	10.26	-10.98	-0.05	-0.85	-1.39	2.87	2.26	-3.03	-0.03
University of New South Wales	3.36	10.90	-1.67	0.60	-2.38	4.26	2.51	0.39	0.83	3.20	-1.04	7.77	2.23
University of Newcastle	2.88	14.70	25.83	4.47	3.66	2.06	8.93	2.93	2.60	2.33	0.20	9.92	3.60
University of Queensland	4.67	7.67	7.94	3.73	4.05	1.80	4.98	2.30	1.64	5.95	0.60	8.30	3.76
University of South Australia	4.27	8.17	21.99	4.07	-2.30	13.42	8.27	0.57	2.52	0.44	-2.83	13.52	2.84
University of Southern Queensland	0.60	20.45	10.44	-4.37	21.12	1.35	8.27	5.12	4.55	-1.13	-3.71	15.27	4.02
University of Sydney	4.47	8.08	4.94	4.35	6.42	8.20	6.07	-0.27	1.22	0.99	0.32	9.38	2.33
University of Tasmania	1.25	4.61	5.21	9.16	-13.42	1.64	1.41	2.17	3.25	4.06	-0.22	2.84	2.42
University of Technology, Sydney	5.87	12.85	7.89	14.89	-11.02	11.46	6.99	2.01	2.32	7.92	-2.14	11.11	4.24
University of Western Australia	1.21	9.21	2.89	3.90	0.91	1.88	3.33	1.67	2.03	4.08	-1.11	5.30	2.39
University of Western Sydney	6.77	5.27	19.08	-0.74	-8.44	11.85	5.63	-0.94	-1.57	-0.11	-1.08	6.70	0.60
University of Wollongong	2.46	13.24	14.65	10.57	-12.72	5.93	5.69	1.91	0.52	6.38	1.23	16.91	5.39
Victoria University of Technology	2.33	0.74	10.60	17.10	3.85	16.52	8.52	-0.04	4.37	5.50	-3.61	8.74	2.99
Mean	3.84	9.47	11.90	5.14	7.28	7.35	7.50	0.83	2.03	4.90	-0.91	9.31	3.23
Standard deviation	3.43	5.87	9.51	8.08	25.29	7.27	5.31	1.97	2.61	3.74	2.25	5.65	1.80
Minimum	-2.84	-4.16	-1.67	-9.39	-23.42	-10.98	-0.05	-5.80	-6.00	-2.75	-5.93	-3.03	-0.03
Maximum	16.78	23.66	41.47	21.90	139.10	24.11	30.08	5.12	7.62	14.21	3.94	26.44	9.21

Table 3
Geometric mean changes in efficiency, technology and productivity by year and university, with six outputs and five inputs, 1998-2003

Year and institution	Efficiency change	Technological change	Pure efficiency change	Scale efficiency change	Total factor productivity change	Total factor productivity rank
1998/1999	1.4	0.6	0.2	1.2	2.0	4
1999/2000	-1.2	0.9	-0.2	-1.0	-0.3	5
2000/2001	-0.5	4.2	-0.6	0.2	3.7	2
2001/2002	-0.9	9.3	-0.4	-0.5	8.3	1
2002/2003	1.0	2.0	0.4	0.6	2.9	3
All years	0.0	3.3	-0.1	0.1	3.3	–
Australian Catholic University	–	-1.4	–	–	-1.4	34
Central Queensland University	2.6	10.1	2.5	0.1	13.0	1
Charles Sturt University	–	6.4	–	–	6.4	8
Curtin University of Technology	–	7.2	–	–	7.2	5
Deakin University	-1.0	0.6	-0.9	-0.2	-0.4	29
Edith Cowan University		2.2	–	–	2.2	20
Flinders University of South Australia	-1.4	0.2	-1.3	–	-1.1	30
Griffith University	0.6	1.5	-1.1	1.7	2.1	23
James Cook University	–	-0.2	–	–	-0.2	28
La Trobe University	–	5.2	–	–	5.2	12
Macquarie University	0.2	6.4	–	0.2	6.6	7
Monash University	–	3.2	–	–	3.2	16
Murdoch University	1.5	-0.3	–	1.5	1.2	27
Northern Territory University	–	2.3	–	–	2.3	19
Queensland University of Technology	-2.0	8.0	-2.5	0.6	5.9	10
Royal Melbourne Institute of Technology	–	6.7	–	–	6.7	6
Southern Cross University	0.9	4.7	1.8	-0.9	5.6	11
Swinburne University of Technology	–	-1.1	–	–	-1.1	30
University of Adelaide	–	2.2	–	–	2.2	20
University of Ballarat	–	7.7	–	–	7.7	3
University of Canberra	-1.2	-0.6	-1.2	–	-1.8	35
University of Melbourne	–	5.0	–	–	5.0	13
University of New England	–	-1.3	–	–	-1.3	33
University of New South Wales	–	1.9	–	–	1.9	25
University of Newcastle	–	3.6	–	–	3.6	15
University of Queensland	–	2.2	–	–	2.2	20
University of South Australia	-2.6	5.5	–	-2.6	2.8	17
University of Southern Queensland	–	1.8	–	–	1.8	26
University of Sydney	0.3	4.5	–	0.3	4.8	14
University of Tasmania	1.4	6.5	–	1.4	7.9	2
University of Technology, Sydney	–	-1.2	–	–	-1.2	32
University of Western Australia	–	6.4	–	–	6.4	8
University of Western Sydney	1.7	5.6	–	1.7	7.4	4
University of Wollongong	–	2.4	–	–	2.4	18
Victoria University of Technology	-2.2	4.4	-1.8	-0.4	2.0	24
All universities	0.0	3.3	-0.1	0.1	3.3	–

Table 4
Geometric mean changes in efficiency, technology and productivity by year and university (including the Australian National University), with six outputs and five inputs, 2000-2003

Year and institution	Efficiency change	Technological change	Pure efficiency change	Scale efficiency change	Total factor productivity change	Total factor productivity rank
2000/2001	-0.5	4.4	-0.6	0.1	3.9	2
2001/2002	-0.9	8.6	-0.4	-0.5	7.6	1
2002/2003	0.7	2.7	0.3	0.4	3.3	3
All years	-0.2	5.2	-0.3	–	4.9	–
Australian Catholic University	–	-0.2	–	–	-0.2	31
Australian National University	–	12.1	–	–	12.1	4
Central Queensland University	5.4	13.4	3.5	1.8	19.6	2
Charles Sturt University	–	11.3	–	–	11.3	5
Curtin University of Technology	–	9.6	–	–	9.6	8
Deakin University	-2.3	-4.3	-2.1	-0.2	-6.5	36
Edith Cowan University	–	3.4	–	–	3.4	20
Flinders University of South Australia	-1.9	0.4	-2.2	0.3	-1.5	32
Griffith University	-6.3	3.7	-5.3	-1.1	-2.9	35
James Cook University	–	1.6	–	–	1.6	28
La Trobe University	–	3.4	–	–	3.4	20
Macquarie University	1.2	9.5	–	1.2	10.8	6
Monash University	–	6.5	–	–	6.5	13
Murdoch University	4.5	1.1	–	4.5	5.7	14
Northern Territory University	–	1.7	–	–	1.7	27
Queensland University of Technology	-3.8	11.7	-4.3	0.5	7.5	11
Royal Melbourne Institute of Technology	7	12.3	6.6	0.3	20.2	1
Southern Cross University	-3.2	6.9	-1.7	-1.6	3.5	19
Swinburne University of Technology	–	-1.8	–	–	-1.8	33
University of Adelaide	–	1.9	–	–	1.9	26
University of Ballarat	–	8.8	–	–	8.8	9
University of Canberra	-1.9	4.7	-1.9	–	2.7	24
University of Melbourne	–	7.6	–	–	7.6	10
University of New England	–	-1.9	–	–	-1.9	34
University of New South Wales	–	3.0	–	–	3.0	22
University of Newcastle	–	3.8	–	–	3.8	18
University of Queensland	–	2.8	–	–	2.7	24
University of South Australia	-6.6	7.4	–	-6.6	0.4	30
University of Southern Queensland	–	3.0	–	–	3.0	22
University of Sydney	0.1	7.4	–	0.1	7.5	11
University of Tasmania	2.2	11.9	1.9	0.3	14.4	3
University of Technology, Sydney	–	1.3	–	–	1.3	29
University of Western Australia	–	5.4	–	–	5.4	15
University of Western Sydney	1.6	8.4	–	1.6	10.2	7
University of Wollongong	–	4.3	–	–	4.3	16
Victoria University of Technology	-3.8	8.2	-3.0	-0.8	4.1	17
All universities	-0.2	5.2	-0.3	0.0	4.9	–

Table 5
Geometric mean changes in efficiency, technology and productivity by year and university, with three outputs and three inputs, 1998-2003

Year and institution	Efficiency change	Technological change	Pure efficiency change	Scale efficiency change	Total factor productivity change	Total factor productivity rank
1998/1999	-1.0	3.2	-1.4	0.4	2.1	4
1999/2000	-0.7	0.6	0.1	-0.8	-0.1	5
2000/2001	0.7	2.4	-0.5	1.2	3.1	3
2001/2002	0.1	11.0	–	0.1	11.1	1
2002/2003	1.8	3.5	2.2	-0.4	5.4	2
All years	0.2	4.1	0.1	0.1	4.3	–
Australian Catholic University	–	2.3	–	–	2.3	26
Central Queensland University	7.3	6.6	6.6	0.7	14.4	1
Charles Sturt University	–	6.4	–	–	6.4	7
Curtin University of Technology	2.6	6.1	1.6	1.0	8.9	3
Deakin University	-1.4	6.5	-2.2	0.8	5.0	13
Edith Cowan University	3.5	0.9	2.6	0.8	4.4	16
Flinders University of South Australia	0.2	4.0	–	0.1	4.2	17
Griffith University	1.2	0.9	1.3	-0.1	2.1	27
James Cook University	-2.4	3.5	-2.2	-0.1	1.0	32
La Trobe University	–	5.1	–	–	5.1	11
Macquarie University	2.2	4.7	–	2.2	7.0	5
Monash University	-0.6	3.6	-0.5	-0.1	3.0	23
Murdoch University	-2.6	4.8	–	-2.6	2.1	27
Northern Territory University	-0.2	2.1	-2.2	2.0	1.8	30
Queensland University of Technology	-1.7	8.9	-3.5	1.9	7.0	5
Royal Melbourne Institute of Technology	-0.6	6.6	–	-0.6	5.9	9
Southern Cross University	-0.6	5.6	0.6	-1.3	4.9	14
Swinburne University of Technology	1.0	–	–	1.0	1.0	32
University of Adelaide	0.5	3.7	0.3	0.2	4.2	17
University of Ballarat	–	5.1	–	–	5.1	11
University of Canberra	-5.2	1.7	-3.8	-1.5	-3.5	35
University of Melbourne	-0.5	4.5	–	-0.5	4.0	21
University of New England	1.4	-0.1	1.8	-0.4	1.2	31
University of New South Wales	–	2.5	–	–	2.5	25
University of Newcastle	1.7	3.0	–	1.7	4.7	15
University of Queensland	–	1.9	–	–	1.9	29
University of South Australia	-0.5	4.7	–	-0.5	4.2	17
University of Southern Queensland	-1.3	5.5	0.7	-2.0	4.1	20
University of Sydney	1.7	4.1	1.6	0.1	5.9	9
University of Tasmania	2.4	4.7	4.0	-1.5	7.3	4
University of Technology, Sydney	-0.7	1.6	-0.8	0.1	0.9	34
University of Western Australia	–	6.3	–	–	6.3	8
University of Western Sydney	3.1	6.4	0.7	2.4	9.7	2
University of Wollongong	0.5	2.8	–	0.5	3.3	22
Victoria University of Technology	-3.8	6.7	-3.4	-0.4	2.6	24
All universities	0.2	4.1	0.1	0.1	4.3	–

Table 6
Geometric mean changes in research and teaching only efficiency, technology and productivity by year and university, with six outputs and five inputs, 1998-2003

	Research only						Teaching only					
Year and institution	Efficiency change	Technological change	Pure efficiency change	Scale efficiency change	Total factor productivity change	Total factor productivity rank	Efficiency change	Technological change	Pure efficiency change	Scale efficiency change	Total factor productivity change	Total factor productivity rank
1998/1999	3.6	4.4	-0.2	3.8	8.2	3	4.4	-5.0	1.6	2.7	-0.8	5
1999/2000	4.0	-6.1	5.3	-1.2	-2.3	5	-4.5	5.4	-2.0	-2.5	0.7	4
2000/2001	1.2	3.7	-4.4	5.9	5.0	4	-2.1	5.1	-3.0	0.9	2.9	2
2001/2002	3.8	7.5	8.5	-4.3	11.7	1	-0.1	10.9	-0.9	0.8	10.8	1
2002/2003	11.3	-1.8	5.2	5.8	9.3	2	-0.2	1.6	1.1	-1.3	1.3	3
All years	4.8	1.4	2.8	1.9	6.3	–	-0.6	3.5	-0.7	0.1	2.9	–
Australian Catholic University	13.9	-3.1	3.2	10.4	10.4	9	–	-2.6	–	–	-2.6	31
Central Queensland University	7.3	-0.5	5.2	2.0	6.8	13	3.5	9.8	3.3	0.2	13.7	1
Charles Sturt University	28.0	-2.3	26.7	1.0	25.1	1	–	6.2	–	–	6.2	9
Curtin University of Technology	2.9	4.2	3.2	-0.3	7.2	12	0.6	6.8	–	0.6	7.5	7
Deakin University	9.9	0.1	10.2	-0.2	10	10	-3.0	-0.1	-3.6	0.7	-3.0	32
Edith Cowan University	10.6	-3.5	11.5	-0.8	6.8	13	-0.2	0.2	–	-0.1	–	26
Flinders University of South Australia	5.9	-0.1	4.3	1.5	5.7	15	-2.9	-0.9	-3.6	0.7	-3.8	34
Griffith University	-3.6	3.5	-5.8	2.3	-0.2	31	4.2	-1.8	4.3	-0.2	2.3	19
James Cook University	-2.5	1.4	-2.4	-0.1	-1.1	33	-1.1	1.9	-1.6	0.5	0.7	24
La Trobe University	-0.1	3.6	-0.5	0.4	3.5	24	1.4	7.7	0.4	1.0	9.3	2
Macquarie University	0.8	3.5	0.9	-0.1	4.3	20	3.0	5.2	–	3.0	8.4	5
Monash University	-2.4	2.8	–	-2.4	0.3	28	1.4	3.9	1.2	0.2	5.3	13
Murdoch University	9.1	6.5	–	9.1	16.2	4	0.4	1.5	–	0.4	1.9	20
Northern Territory University	5.5	-0.9	5.4	0.1	4.6	18	1.0	-0.2	–	1.0	0.8	23
Queensland University of Technology	7.5	6.0	7.5	0.1	14.0	5	-3.7	9.5	-4.8	1.2	5.5	12
Royal Melbourne Institute of Technology	9.9	7.2	–	9.9	17.9	3	–	3.1	–	–	3.1	17
Southern Cross University	8.3	0.1	3.5	4.7	8.5	11	0.5	5.1	2.1	-1.6	5.7	11
Swinburne University of Technology	1.6	-1.5	–	1.6	0.2	29	-1.5	-0.8	-1.4	-0.1	-2.3	30
University of Adelaide	–	4.5	–	–	4.5	19	0.5	2.0	0.6	-0.1	2.5	18
University of Ballarat	–	5.1	–	–	5.1	17	2.5	6.3	-0.4	2.9	8.9	3
University of Canberra	-4.3	0.8	-4.3	-0.1	-3.5	35	-4.7	1.7	-4.6	-0.1	-3.1	33
University of Melbourne	-1.0	4.0	–	-1.0	3.0	26	1.1	4.0	–	1.1	5.1	14
University of New England	2.3	-2.2	1.1	1.2	0.1	30	–	-1.2	-0.5	0.5	-1.1	28
University of New South Wales	–	3.7	–	–	3.7	23	-2.4	4.3	-1.8	-0.7	1.8	21
University of Newcastle	0.6	3.7	–	0.6	4.3	20	-1.8	3.0	-1.4	-0.4	1.2	22
University of Queensland	-0.2	-0.5	–	-0.1	-0.7	32	-3.1	3.6	-2.8	-0.3	0.4	25
University of South Australia	19.5	-0.2	–	19.5	19.2	2	-11	5.4	–	-11.0	-6.2	35
University of Southern Queensland	0.6	-2.0	-3.3	4	-1.4	34	1.0	3.2	–	1.0	4.2	15
University of Sydney	9.8	1.4	8.9	0.8	11.3	7	-0.8	8.2	-2.4	1.7	7.3	8
University of Tasmania	4.5	-1.1	3.6	0.8	3.3	25	1.6	7.2	1.1	0.4	8.9	3
University of Technology, Sydney	-1.0	3.4	-1.8	0.8	2.3	27	–	-1.2	–	–	-1.2	29
University of Western Australia	7.7	-2.3	6.6	1.0	5.2	16	–	8.4	–	–	8.4	5
University of Western Sydney	14	-0.4	13.7	0.3	13.6	6	2.3	3.8	–	2.3	6.2	9
University of Wollongong	-0.1	4.0	–	-0.1	3.9	22	-2.3	6.2	-2.0	-0.3	3.7	16
Victoria University of Technology	8.5	2.5	5.5	2.9	11.2	8	-4.4	4.1	-4.5	0.1	-0.4	27
All universities	4.8	1.4	2.8	1.9	6.3	–	-0.6	3.5	-0.7	0.1	2.9	–