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 inputs included in the analysis are full-time equivalent academic and non-academic staff, non-labour expenditure and undergraduate and postgraduate student load and the 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 between -1.8 percent and 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.

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

JEL classifications: C61; D24; I29; O30

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 include: declining public funding per student, massive growth in international student numbers, increasingly

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competitive markets for international and domestic fee-paying students, rising expenditures on university infrastructure, heightened competition for research funding and academic expertise, 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 academic and non-academic staff numbers increased a mere 5% and 10% respectively and non-labour expenditure by just 26%. 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 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 [see, for example, Madden et al. (1997), Abbott and Doucouliagos (2003a; 2003b), Carrington et al. (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 itself 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 in the final section.

2. Malmquist indexes of productivity and technical change

The methodology employed to calculate productivity change and decompose it into its technical efficiency and technological components is the nonparametric Malmquist index [for a practical introduction to efficiency and productivity measurement see Coelli, Rao and Battese (1998): Charnes, Cooper, Lewin and Seiford (1993), Cooper Seiford and Tone (2000) and Cooper, Seiford and Zhu (2004) provide discussion of nonparametric methods]. The approach itself has been applied in a number of service industry contexts, including healthcare [see, for instance, Maniadakis and Thanassoulis (2000) and Ventura, Gonzalez and Carcaba (2004) with a useful empirical survey in Worthington (2004)] and financial services [see Worthington (1999), Mahlberg and Url (2003) and Sturm and Williams (2004)]. The only known education study to use the Malmquist index approach is Flegg, Allen, Field and

Thurlow (2004), but frontier efficiency measurement approaches more generally have been widely employed [see, for example, Tomkins and Green (1988), Beasley (1990; 1995), Johnes and Johnes (1993; 1995), Johnes (1995), Glass, McKillop and Hyndman (1995), Athanassopoulos and Shale (1997)] as surveyed in Worthington (2001).

The framework can be illustrated by Figure 1 following Coelli, Rao and 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 and Battese (1998), the output-based Malmquist productivity change index may be formulated as:

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

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 growth between the two periods. An equivalent way of writing this index is:

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

or $M = E \cdot P$ where M (the Malmquist total factor productivity index) is the product of a measure of technical progress P (the two ratios in the square bracket) as measured by shifts in the frontier measured at period t + 1 and period t (averaged geometrically) and a change in efficiency E over the same period (the term outside the square bracket).

In order to calculate these indices it is necessary to solve several linear programs. Assume there are N universities and that each university consumes varying amounts of K different inputs to produce M outputs. The ith university is therefore represented by the vectors $x_i y_i$ and the (K×N) input matrix X and the (M×N) output matrix Y represent the data of all universities in the sample. The purpose is to construct a nonparametric envelopment frontier over the data points such that all observed points lie on or below the production frontier. The calculations exploit the fact that the output distance functions (D) used to construct the Malmquist index are the reciprocals of Farrell's (1957) technical efficiency measures. They therefore bear a close resemblance to the Charnes, Cooper and Rhodes (1978) data envelopment analysis model. The first two linear programs are where the technology and the observation to be evaluated are from the same period, and the solution value is less than or equal to unity. The second two linear programs occur where the reference technology is constructed from data in one period, whereas the observation to be evaluated is from another period. Assuming constant returns-to-scale to start with, the following linear programs are used:

$$\begin{aligned} \left[D_O^{t+1}(y_{t+1}, x_{t+1}\right]^{-1} &= \max\nolimits_{\theta,\lambda} \phi \\ s.t. -\phi y_{i,t+1} + Y_{t+1}\lambda &\geq 0 \\ x_{i,t+1} - X_{t+1}\lambda &\geq 0 \\ \lambda &\geq 0 \end{aligned} \tag{3}$$

$$\begin{aligned} \left[D_O^{t}(y_{t}, x_{t}\right]^{-1} &= \max\nolimits_{\phi,\lambda} \phi \\ s.t. -\phi y_{i,t} + Y_{t}\lambda &\geq 0 \\ x_{i,t} - X_{t}\lambda &\geq 0 \\ \lambda &\geq 0 \end{aligned} \tag{4}$$

$$\begin{aligned} \left[D_O^{t+1}(y_{t}, x_{t}\right]^{-1} &= \max\nolimits_{\phi,\lambda} \phi \\ s.t. -\phi y_{i,t} + Y_{t}\lambda &\geq 0 \\ x_{i,t} - X_{t}\lambda &\geq 0 \\ \lambda &\geq 0 \end{aligned} \tag{5}$$

$$\begin{aligned} \left[D_O^{t}(y_{t+1}, x_{t+1}\right]^{-1} &= \max\nolimits_{\phi,\lambda} \phi \\ s.t. -\phi y_{i,t+1} + Y_{t}\lambda &\geq 0 \\ x_{i,t+1} - X_{t}\lambda &\geq 0 \\ \lambda &\geq 0 \end{aligned} \tag{6}$$

This approach can be extended by decomposing the constant returns-to-scale technical efficiency change into scale efficiency and pure technical efficiency components. This involves calculating further linear programs where the convexity constraint $N1'\lambda=1$ is introduced to programs (3) to (6). Once again, it is obvious that the output distance function calculated here is the reciprocal of an output-orientated Farrell measure of technical efficiency calculated relative to technology satisfying variable returns-to-scale vis-à-vis Banker, Charnes and Cooper (1984).

By running these programs with the same data under a constant returns-to-scale (without convexity constraint) and variable returns-to-scale (with convexity constraint), measures of overall technical efficiency (*E*) and 'pure' technical efficiency (*PT*) are obtained. Dividing overall technical efficiency (*E*) by pure technical efficiency then yields a measure of scale efficiency (*S*). Using these models, it is thus possible to provide four efficiency/productivity indices for each university and a measure of technical progress over time. These are: (i) technical efficiency change (*E*) (i.e. relative to a constant returns-to-scale technology); (ii) technological change (*P*); (iii) pure technical efficiency change (*PT*) (i.e. relative to a variable returns-to-scale technology); (iv) scale efficiency change (*S*); and (v) total factor productivity

(M) change. Recalling that M indicates the degree of productivity change, then if $M > 1$ then productivity gains occur, whilst if $M < 1$ productivity losses occur. Regarding changes in efficiency, technical efficiency increases (decreases) if and only if E is greater (less) than one. An interpretation of the technological change index is that technical progress (regress) has occurred if P is greater (less) than one.

An assessment can also be made of the major sources of productivity gains/losses by comparing the values of E and P. If $E > P$ then productivity gains are largely the result of improvements in efficiency, whereas if $E < P$ productivity gains are primarily the result of technological progress. In addition, recall that overall technical efficiency is the product of pure technical efficiency and scale efficiency, such that $E = PT \times S$. Thus, if $PT > S$ then the major source of efficiency change (both increase and decrease) is improvement in pure technical efficiency, whereas if $PT < S$ the major source of efficiency is an improvement in scale efficiency. Subtracting one from any index provides the change in efficiency, technology or productivity from one period to the next. Further details on the interpretation of these indices may be found in Charnes *et al*. (1993).

3. Specification of inputs and outputs

The data used in this study consists of annual observations of 35 Australian universities over the period 1998 to 2003. This is longest and most recent period where consistent data on university inputs and outputs has been collected by the Commonwealth Department of Education, Science and Training (DEST). The remaining three universities are excluded through the technical requirement for a balanced panel of data: the Australian National University (non-separable research funding in 1998 and 1999 associated with the Institute of Advanced Studies) and the Sunshine Coast and Notre Dame Australia universities (both in operation only since 2000). All data is sourced from the Department of Education, Science and Training. The Australian Bureau of Statistic's 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 et al. (2004), but also has a common conceptualisation of university performance as Beasley (1995), Johnes and Johnes (1993; 1995), Madden et al. (1997) and Athanassopoulos and Shale (1997). Six categories of output are employed. These are: undergraduate, postgraduate and PhD completions, the dollar income from national competitive and industry grants and publications. Unmistakably, the numbers of undergraduate and postgraduate degrees awarded are an obvious measure of output for any university. Similarly, research is also an important output for universities as signified with ongoing government funding being currently distributed across universities by a performance-based formula comprising research income and publications and doctoral student completions. To some extent, the dollar value of research income also reflects the market value of university research output. And clearly, there are interrelationships between the research and teaching dimensions of university performance.

Nevertheless, there are two obvious limitations with the selected output specification. First, there is no direct allowance for quality such that the degrees of graduates from all universities are viewed in the same way, and a dollar of research income from any or all sources is one and the same. Putting aside the lack of alternative measures, this is entirely consistent with current policy. For example, Commonwealth funding for students by discipline is identical across universities, DEST makes no distinction between different and among national competitive and industry grants, and among the publications recognised as research performance (books, book chapters and refereed journal articles and conference proceedings) there is no attempt to distinguish between high and low quality outcomes. Second, there is also 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, the selected approach assumes such ‘unmeasured’ outputs are common to all universities.

The inputs included in the analysis are full-time equivalent academic and non-academic staff, non-labour expenditure (comprising academic activities and research, libraries, other academic support services, student services, public services, buildings and grounds and administration and other general institution services), and undergraduate and postgraduate student load. The input specification is comparable to Flegg’s et al. (2004) study of British universities. Unfortunately, the data does not allow the separation of academic staff into teaching and research or research only, 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 way of highlighting changes over the sample period, geometric mean growth rates for all outputs and inputs are calculated and presented in Table 2. The unweighted average of all outputs and inputs for each university are included in the last two columns. Across the sector, undergraduate completions grew by 3.84 percent annually between 1998 and 2003 ranging between -2.84 percent (Ballarat) and 16.78 percent (Central Queensland). Postgraduate completions grew by 9.47 percent with a range of -4.16 percent (New England) and 23.66 percent (Central Queensland). Other output growth rates (range in brackets) were 11.90 percent for doctoral completions (-1.67 New South Wales to 41.47 Ballarat), 5.14 percent for national competitive grants (-9.39 Macquarie to 21.90 Ballarat), 7.28 percent for industry grants (-23.42 Charles Sturt to 139.10 Australian Catholic University) and 7.35 percent for publications (-10.98 New England to 24.11 Charles Sturt).

These increases in output (range in brackets) were generally matched by an increase in inputs: a 0.83 percent increase in academic staff (-5.80 Northern Territory to 5.12 Southern Queensland) and a 2.03 percent increase in non-academic staff (-6.00 Northern Territory to 7.62 Central Queensland), a 4.90 percent increase in non-labour inputs (-2.75 Flinders to 14.21 Central Queensland), a 0.91 percent fall in undergraduate load (-5.93 Royal Melbourne to 3.94 Charles Sturt) and a 9.31 percent in postgraduate load (-3.03 New England to 26.44 Ballarat). Across all universities, outputs rose on average by 3.23 percent and inputs by 7.50 percent. But there is a remarkable degree of diversity in the relative rates of growth for each of the universities. Universities with high relative rates of input to output growth include Australian Catholic, Ballarat, Deakin and Edith Cowan and those with high relative rates of output to input growth include Tasmania, La Trobe, Canberra and Macquarie. Only one university (New England) experienced negative growth rates in both inputs and outputs over the sample period.

<TABLE 2 HERE>

By and large, the distributional properties of all seven variables in Table 1 appear non-normal. Given that the sampling distribution of skewness is normal with mean 0 and standard deviation of $\sqrt{6/T}$ where T is the sample size, many of the series are significantly skewed. Since these are also positive they signifying the greater likelihood of observations lying above the mean than below. Across each of the years in the sample period, the most highly skewed variables are PhD completions, national competitive and industry grants. The kurtosis, or degree of excess, across some variables is also large, thereby indicating leptokurtic distributions with extreme observations. Given the sampling distribution of kurtosis is normal with mean 0 and standard deviation of $\sqrt{24/T}$ where T is the sample size, then many estimates are once again statistically significant at any conventional level. PhD completions, national competitive and industry grants are again highly leptokurtic. That said, the nonparametric, nonstochastic methodology used not rely upon conventional asymptotic distributional assumptions, and it is only in the case of the most extreme outliers that a decision-making unit would be excluded. As an example, in their study of forty-five equally-diverse British universities, Flegg et al. (2004) only excluded the London and Manchester business schools, and then only because these had no undergraduates at all.

4. Empirical results

Table 3 presents the geometric mean changes in efficiency, technology and productivity 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 change over the period. The second is to decompose changes in productivity 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 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 is also a relative concept: a larger university may be more productive (producing more outputs), but its productivity 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 last row of Table 3, there was an annual mean increase in total factor productivity of 3.3 percent for the period 1998 to 2003 across the university sector. Given that productivity change is the sum of technical efficiency and technological change, the major cause of productivity improvements can be ascertained by comparing the values of the efficiency change and technological change. Put differently, the productivity gains described 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 sustained improvement in productivity over the period 1998-2003 is the result of a sustained 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 and Kulys (2003), for example, identify high multifactor productivity 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 Flegg’s et al. (2004) study of British universities over the earlier period 1980/81 to 1992/93 which suggested an arithmetic mean growth of 4.0 percent.

However, these figures obscure very different results across a number of universities which are ranked by their total factor productivity in the final column. Central Queensland, for example, had a mean productivity improvement 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, most of the technical efficiency gain was composed of improvement in pure technical efficiency (2.5 percent) with a smaller contribution through scale efficiency (0.1 percent). By way of comparison, Tasmania was ranked second in terms of productivity (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 a productivity gain of 7.7 percent entirely attributable to technological progress and no improvements in efficiency. 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 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 level of total factor productivity 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 all of these instances, the decline in productivity was not the result of inefficiency, rather contraction in their best-practice frontier. At Canberra undergraduate load and national competitive and grants fell on average by 6.90, 11.74 and 3.22 percent, respectively; at Australian Catholic undergraduate and postgraduate completions fell by -0.42 and -2.07 percent and inputs increased massively by 30.08 percent while at New England contractions in postgraduate completions (-4.16 percent), national competitive grants (-0.95 percent) and publications (-10.98 percent) were accompanied by a reduction in full-time non-academic staff (-1.39 percent) and postgraduate load (-3.03 percent).

Further insights are gained by examining the changes in pure technical and scale 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 total factor productivity. Two institutions that improved their productivity 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 9.21 percent and Southern Cross by a more modest 3.30

percent while limiting inputs to 8.73 percent. 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, 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. Other universities whose productivity benefited from improvements in scale efficiency include Griffith (1.7 percent), Western Sydney (1.7 percent) and Murdoch (1.5 percent).

In order to understand the sources of these productivity changes two additional specifications of university productivity are examined. The first of these focuses on 'research-only' productivity and the second on 'teaching-only' productivity. 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 are specified only as 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.

<TABLE 4 HERE>

The geometric means for the efficiency, technology and productivity percentage changes for both approaches are presented in Table 4. Figures 2, 3 and 4 graph the overall, research-only and teaching-only changes in productivity, technical, pure technical and scale efficiency and technology for the sector. 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, 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 across the sector averaged 6.3 percent. Inefficiency averaged 4.8 percent with 2.8 percent in pure technical inefficiency and 1.9 percent in scale inefficiency. Just 1.4 percent of the productivity improvement occurred due to technological improvements. On the other hand, for teaching only productivity 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.

While care must be taken in the interpretation of these results due to the overlap in teaching and research-related inputs, it is clear that much of the overall productivity improvement in universities over this period is 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 total factor productivity. While Central Queensland recorded a higher than average rise in research-only productivity (6.8 percent, ranked 13th) it was largely through improvement in teaching-only productivity (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 paper examines the productivity of Australian universities over the period 1998-2003. The inputs included in the analysis are full-time equivalent academic and non-academic staff, non-labour expenditure and undergraduate and postgraduate student load and the 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 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 gains.

However, separate analyses of research-only and teaching-only productivity indicate that annual productivity growth in research 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 is mostly associated with the removal of inefficiency rather than technological improvement, whereas the teaching gains are mainly sourced from technological gains and very little efficiency improvements. 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. These are primarily capital-based improvements and this is reinforced by the low rates of growth in (especially) academic and (less-so) 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 also indicates that most universities are operating near the best-practice frontier suggesting the widespread diffusion of management and teaching practices aimed at improving outputs.

The decomposition of research-only productivity is also unsurprising. Certainly there have been avenues for improving research productivity 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 has assisted these developments. But mostly this has 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 improvements in a function that is little changed for many decades.

As a rule, the largest productivity improvements have been found in smaller, newer universities rather than the larger, older universities. This suggests that these universities are in a better position to quickly exploit some of the primary sources of productivity gains: advances in the nature of the processes employed; improvements in the effectiveness in which operations are integrated; increases in the scale of production; advances in the quality of inputs; and changes in the scope of operations. As these institutions mature, at least some of these will be exhausted and productivity will start to slow, but is also likely that that some sources of productivity 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 lower level of inefficiency, further gains will rely on technical innovation. This remains a challenge to the sector.

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FIGURE 1 Efficiency, technology and productivity changes

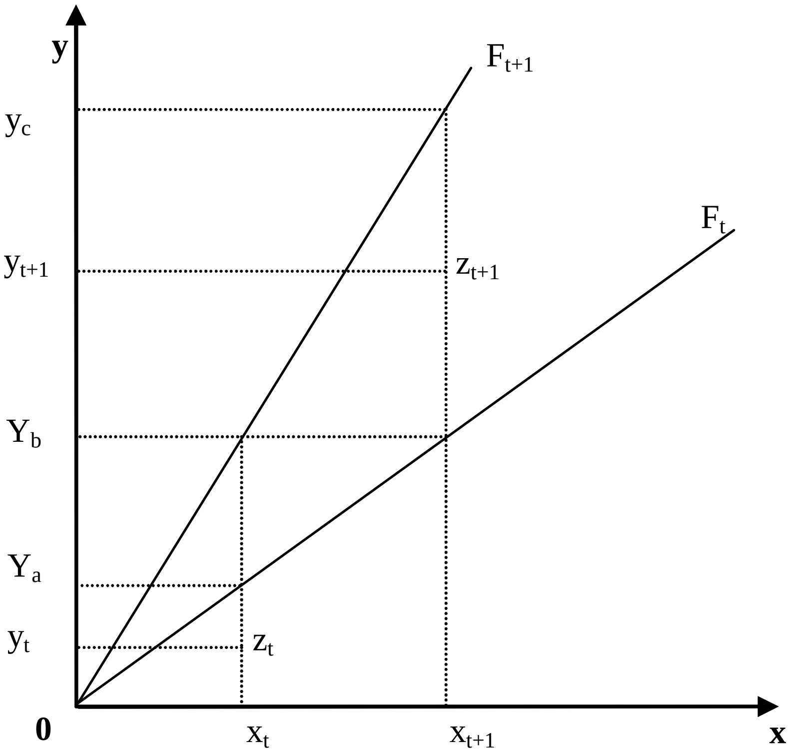


TABLE 1 Selected descriptive statistics of university outputs and inputs by year, 1998-2003

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	27216	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	25140	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	26932	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	10271	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	27423	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	11550	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	33949	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	11622	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	35593	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 academic activities and research, 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)	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 outputs	All inputs
Australian Catholic University	-0.42	-2.07	10.76	19.43	139.10	13.69	1.40	4.56	3.04	-0.21	1.51	2.06	30.08
Central Queensland University	16.78	23.66	20.11	2.75	12.48	8.41	1.41	7.62	14.21	-0.06	22.88	9.21	14.03
Charles Sturt University	7.33	11.29	22.87	17.52	-23.42	24.11	-0.26	1.52	0.87	3.94	11.28	3.47	9.95
Curtin University of Technology	6.53	12.61	18.02	2.43	5.98	2.24	2.17	4.43	3.96	-4.07	8.96	3.09	7.97
Deakin University	1.09	7.90	12.20	16.17	23.40	12.33	2.62	0.91	6.28	-3.53	8.67	2.99	12.18
Edith Cowan University	4.33	10.00	20.71	2.64	8.38	8.71	-1.34	0.23	2.46	0.42	8.88	2.13	9.13
Flinders University of South Australia	0.49	18.72	-0.24	-7.69	5.28	-1.54	-2.10	1.79	-2.75	0.72	9.17	1.36	2.50
Griffith University	3.86	12.97	8.79	3.92	6.30	9.11	2.64	4.32	4.16	0.77	13.71	5.12	7.49
James Cook University	6.61	8.98	1.67	-4.61	13.96	8.05	0.36	6.87	7.73	3.35	4.07	4.47	5.78
La Trobe University	0.92	11.40	5.64	-4.22	5.32	0.05	-0.84	3.62	6.26	-0.01	10.14	3.83	3.18
Macquarie University	5.95	12.96	-0.60	-9.39	6.90	4.29	1.19	-1.90	9.71	-0.98	10.49	3.70	3.35
Monash University	5.91	10.68	5.88	2.89	14.34	6.01	2.50	3.36	4.31	-4.32	12.19	3.61	7.62
Murdoch University	3.15	8.85	4.56	9.34	11.09	3.62	1.33	1.46	7.12	-1.22	2.76	2.29	6.77
Northern Territory University	-0.18	8.07	16.12	8.28	8.81	3.53	-5.80	-6.00	10.82	1.07	2.98	0.61	7.44
Queensland University of Technology	3.50	1.40	2.47	2.04	12.84	9.22	-0.04	0.93	6.30	0.03	3.59	2.16	5.25
Royal Melbourne Institute of Technology	0.89	4.00	14.04	0.78	0.24	16.41	0.92	4.71	6.82	-5.93	8.07	2.92	6.06
Southern Cross University	9.31	5.04	28.67	5.27	-10.03	14.14	-1.19	1.51	3.51	0.72	11.96	3.30	8.73
Swinburne University of Technology	4.49	6.02	12.20	19.30	-9.23	18.06	3.80	0.22	12.62	-3.96	12.22	4.98	8.47
University of Adelaide	3.76	18.08	6.41	5.77	4.83	2.47	0.51	-0.91	1.67	-0.43	5.47	1.26	6.89
University of Ballarat	-2.84	12.87	41.47	21.90	14.21	22.69	-1.00	4.58	8.93	-1.01	26.44	7.59	18.38
University of Canberra	4.18	7.26	21.67	-6.90	-11.74	0.46	2.28	2.59	3.56	-3.22	9.53	2.95	2.49
University of Melbourne	6.26	9.01	10.14	5.38	15.64	1.95	1.54	1.70	7.55	-2.87	7.98	3.18	8.06
University of New England	2.51	-4.16	3.05	-0.95	10.26	-10.98	-0.85	-1.39	2.87	2.26	-3.03	-0.03	-0.05
University of New South Wales	3.36	10.90	-1.67	0.60	-2.38	4.26	0.39	0.83	3.20	-1.04	7.77	2.23	2.51
University of Newcastle	2.88	14.70	25.83	4.47	3.66	2.06	2.93	2.60	2.33	0.20	9.92	3.60	8.93
University of Queensland	4.67	7.67	7.94	3.73	4.05	1.80	2.30	1.64	5.95	0.60	8.30	3.76	4.98
University of South Australia	4.27	8.17	21.99	4.07	-2.30	13.42	0.57	2.52	0.44	-2.83	13.52	2.84	8.27
University of Southern Queensland	0.60	20.45	10.44	-4.37	21.12	1.35	5.12	4.55	-1.13	-3.71	15.27	4.02	8.27
University of Sydney	4.47	8.08	4.94	4.35	6.42	8.20	-0.27	1.22	0.99	0.32	9.38	2.33	6.07
University of Tasmania	1.25	4.61	5.21	9.16	-13.42	1.64	2.17	3.25	4.06	-0.22	2.84	2.42	1.41
University of Technology, Sydney	5.87	12.85	7.89	14.89	-11.02	11.46	2.01	2.32	7.92	-2.14	11.11	4.24	6.99
University of Western Australia	1.21	9.21	2.89	3.90	0.91	1.88	1.67	2.03	4.08	-1.11	5.30	2.39	3.33
University of Western Sydney	6.77	5.27	19.08	-0.74	-8.44	11.85	-0.94	-1.57	-0.11	-1.08	6.70	0.60	5.63
University of Wollongong	2.46	13.24	14.65	10.57	-12.72	5.93	1.91	0.52	6.38	1.23	16.91	5.39	5.69
Victoria University of Technology	2.33	0.74	10.60	17.10	3.85	16.52	-0.04	4.37	5.50	-3.61	8.74	2.99	8.52
Mean	3.84	9.47	11.90	5.14	7.28	7.35	0.83	2.03	4.90	-0.91	9.31	3.23	7.50
Standard deviation	3.43	5.87	9.51	8.08	25.29	7.27	1.97	2.61	3.74	2.25	5.65	1.80	5.31
Minimum	-2.84	-4.16	-1.67	-9.39	-23.42	-10.98	-5.80	-6.00	-2.75	-5.93	-3.03	-0.03	-0.05
Maximum	16.78	23.66	41.47	21.90	139.10	24.11	5.12	7.62	14.21	3.94	26.44	9.21	30.08

TABLE 3 Geometric mean changes in efficiency, technology and productivity by year and university, 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 research and teaching only efficiency, technology and productivity by year and university, 1998-2003

Year and institution	Research only						Teaching only					
	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	

FIGURE 2 Cumulative changes in university efficiency, technology and productivity, 1998-2003

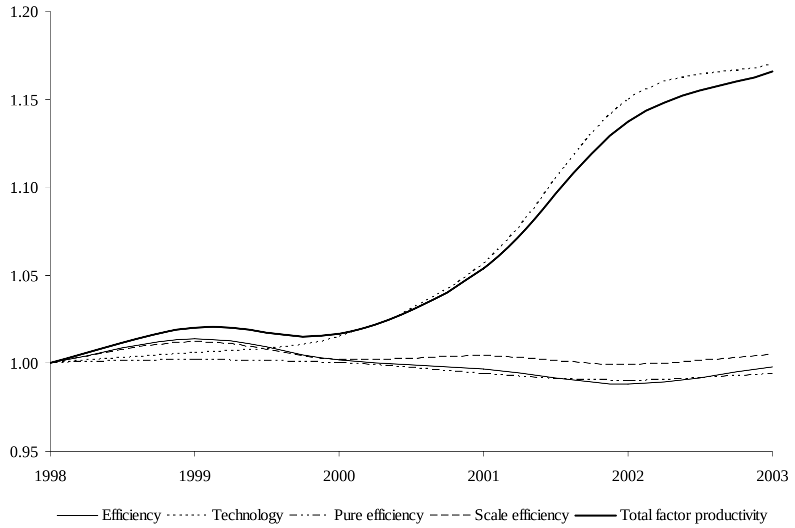


FIGURE 3 Cumulative changes in research efficiency, technology and productivity, 1998-2003

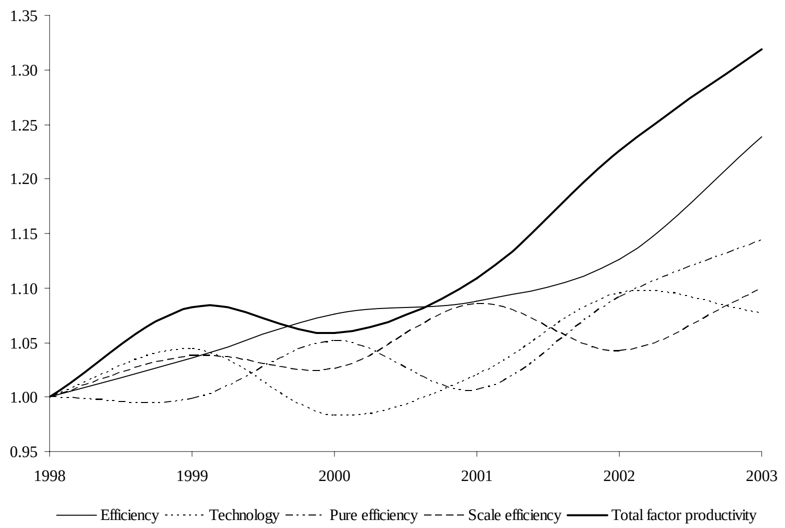
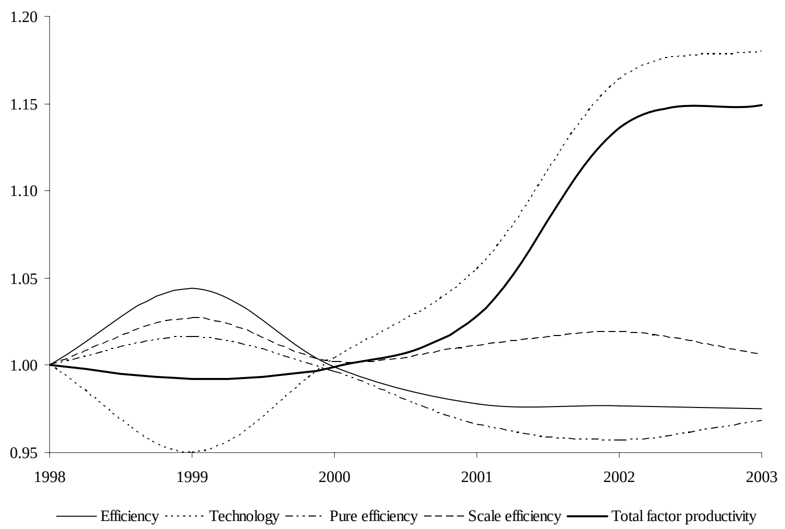


FIGURE 4 Cumulative changes in teaching efficiency, technology and productivity, 1998-2003



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