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Abstract

This paper presents new evidence on research and teaching productivity in universities. The findings are based on a panel that covers 1981-1999 and includes 102 top U.S. universities. Faculty size grows at 0.6 percent per year, compared with growth of 4.9 percent in the industrial science and engineering workforce. Measured by papers and citations per researcher, productivity grows at 1.4-6.7 percent per year and productivity and its rate of growth are higher in private than public universities. Measured by baccalaureate and graduate degrees per teacher, teaching productivity grows at 0.8-1.1 percent per year and growth is faster in public than private universities.

A decomposition analysis shows that growth in research productivity within universities exceeds overall growth. This is because research shares grow more rapidly in universities whose productivity grows less rapidly. Likewise the research share of public universities increases even though productivity grows less rapidly in public universities. Together these findings suggest that allocative efficiency of U.S. higher education declined during the late 20th century.

Regression analysis of individual universities finds that R&D stock, endowment, and post-doctoral students increase research productivity, that the effect of nonfederal R&D stock is less, and that research is subject to decreasing returns. Since the nonfederal R&D share grows and is much higher in public universities, this could account for some of the rising allocative inefficiency. The evidence for decreasing returns in research, which are greater than in teaching, suggests limits on the ability of more efficient institutions to expand and implies that differences in the scale of the teaching function are the primary reason for differences in university size. Besides all this the data strongly hint at growing financial pressures on U.S. public universities.

I. Introduction

This paper presents new evidence on the productivity of U.S. universities. Our interest in this subject originates with recent developments in U.S. higher education that strike us as noteworthy, possibly even disturbing. First, despite their high state, growth of employment and output in top U.S. research universities has slowed in recent years[1]. And second, growth of university research has not kept pace with that of industrial research. This appearance of strain is linked to changes in funding, in which the federal share of university R&D has declined over time. Given the trends and the reliance that firms place on universities, an analysis seems warranted to see whether the slowdown reflects a fundamental decline in university prospects. We find that research productivity grows at a healthy rate but the allocation of R&D has grown less efficient over time. While this has interfered with aggregate productivity growth, increasing budget stringency, especially in public universities, may be the root cause.

The empirical analysis is based on a panel of 102 top U.S. universities, 68 of which are public and 34 private, whose outputs and inputs we observe during 1981-1999. A key feature of our analysis is its separation of productivity into research and teaching, with most of our emphasis placed on research, owing to data availability. The approach assumes that research and teaching activities are on the whole separable. In one sense, though, our approach makes a virtue out of necessity. Price index numbers for research and teaching that could combine the two into a single index are missing for higher education[2].

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[1] Data on the top 200 universities world-wide in The Times Higher Education Supplement suggest first, the preeminence of U.S. universities; and second, erosion of this preeminence. Fifty U.S. schools are in the top 200. Where a lower rank is better, the mean for 27 U.S. privates is 67.7 in 2004 and 60.7 in 2005; for 23 publics the rank is 72.5 in 2004 and 94.8 in 2005; the mean U.S. rank falls from 69.9 to 76.4. Shanghai Jiao Tong University ranks 100 schools worldwide in 2003-2005. In 2003 58 U.S. universities are in the top 100, while 53 appear in 2005. The rankings of U.S. universities improve, but since several publics drop out, it is not clear what to make of this. Both rankings are controversial. The Times uses employer evaluations while the Shanghai ranking uses a weighted average of objective data on prizes, papers, citations, and the like. I thank Amanda Goodall for these references.

[2] In the future, the R&D satellite accounts at the U.S. Bureau of Economic Analysis could fill this gap.

The definition of productivity is output per faculty-equivalent in research and teaching. Research output is papers and citations; teaching output consists of undergraduate and graduate degrees; and numbers of faculty are divided into researchers and teachers. Armed with these measures we begin the empirical work with a description of research and teaching productivity. Next we decompose productivity growth into sources within and between universities, and also groups of public and private universities. Finally, using regression analysis we examine the determinants of productivity in individual universities.

Beginning with trends we find that numbers of faculty grow at 0.6 percent per year. This is demonstrably low compared with the growth of scientists and engineers in U.S. industry. In all universities during 1981-1999 full-time faculty grow at 1.5 percent a year, while all faculty grow at two percent (National Science Board 2004, volume 2, table 5-17). By comparison growth in the industrial science and engineering workforce is 4.9 percent a year during 1980-2000 (National Science Board 2004, volume 1, chapter 3). The university sector is clearly a less important employer of U.S. scientists and engineers than it was in 1981.

We find besides that researchers increase more rapidly than teachers. By our reckoning researchers grow at 1.4 per cent a year while teachers grow at 0.3 percent. At the same time papers per researcher grow at 1.4 percent and citations to these papers grow at 6.7 percent. Research productivity is clearly rising. A cautionary note is that growth in citations and real research growth are not necessarily the same, given the falling cost of citations and worldwide growth in the number of citing researchers[3].

Research productivity in private universities is roughly twice that of public universities. The growth rate of research productivity is also greater in private universities, where papers and citations grow at 2.2 and 8.6 percent per year, than in public universities, where growth is

[3] See the remarks of Hall, Jaffe and Trajtenberg in Ch. 13 of Jaffe and Trajtenberg (2002).

respectively 1.2 and 6.2 percent. The growth rate of research productivity is therefore two-thirds to one third higher in private universities.

Findings on teaching productivity are as follows. The 102 universities produce 4.5 undergraduate degrees per teacher and 2.6 graduate degrees. Undergraduate degrees are 50 percent lower per teacher in private universities, but then graduate degrees per teacher are 50 percent higher in these universities. So relative productivity in the two sets of institutions is roughly equal. Over time, however, teaching productivity drops slightly in private universities, while it increases at one percent a year in public schools[4]. These quantity indexes do not capture changes in the value of higher education, nor do they capture changes in quality, but they represent a start on the problem of measuring teaching productivity.

Besides the study of trends we examine sources of growth in aggregate productivity. By this we mean a shift-share analysis that decomposes aggregate growth into growth within universities, growth between universities, and the covariance of growth in shares and productivity growth. Findings from the decomposition are these. Across all universities the within-university component of growth accounts for more than 100 percent of growth in research output. The between-university contribution is smaller but remains positive. But the covariance of growth in research shares with growth in research productivity is negative. This implies that research shares grow faster in universities where productivity growth is slower.

The decomposition yields similar results within groups of private and public universities. The covariance term is always negative and research grows faster in universities where research productivity grows more slowly. This result suggests growing allocative inefficiency in research in higher education. Analysis of sources of growth in teaching productivity tells a similar story.

[4] The comparison between top 10 research universities and non-top 10 schools is similar.

More than 100 percent of growth is accounted for by the within component, the between component is small but positive, and the covariance term is strictly negative.

Regression analysis of research and teaching productivity concludes the empirical work. We find that R&D, endowment, and post-doctoral students increase research productivity but that research is subject to decreasing returns. In public universities (but not private) there is evidence that graduate students contribute to research productivity. The nonfederal R&D stock in a university is linked to a decline in research productivity. This result disappears when fixed effects are included so that we are unable to identify a within-university effect of nonfederal R&D. One interpretation is that nonfederal funds are subject to earmarking and are awarded under less stringent competitive conditions. Another is that the goal of nonfederal funds is less to produce research than it is to produce information. Regardless of the interpretation, the share of nonfederal funds in university R&D stocks grows by 19 percent over the sample period. Overall, it comprises 40 percent of funding in the publics versus 20 percent in the privates. It could be a factor in productivity differences among public and private universities.

Regression analysis finds that undergraduate teaching productivity increases with enrollment, and (in public universities) with graduate assistants. In public universities state appropriations are linked to a decline in undergraduate degrees per teacher. Production is not subject to decreasing returns to the same degree as research, suggesting that variation in university size is primarily a matter of teaching and not research.

Graduate teaching productivity increases with graduate students and R&D. However, the output of graduate degrees decreases with the nonfederal share of R&D, suggesting that unlike federal R&D nonfederal funds are not for the support of graduate students. Reassuringly, graduate students are at least as important in their own education as they are in faculty research.

The rest of the paper consists of five sections. Section II describes productivity measurement and presents identities that decompose productivity growth into within, between, and covariance components. In addition the section specifies productivity regressions. Section III discusses the database and presents descriptive statistics. Section IV carries out the decomposition analysis of productivity growth. Regression findings are presented in Section V. Section VI is a discussion and conclusion, with emphasis on the challenges facing public universities in the U.S.

II. Analytical Framework

A. Productivity Definitions

The productivity index that we use in this paper is output per faculty member[5]. But university faculty produce both research and teaching. Can labor productivity be measured separately for the two outputs? Our best but also very imperfect answer is yes. We can exploit expenditure shares on research and teaching to construct estimates of research and teaching faculty-equivalents and labor productivity in research and teaching. This of course assumes that these outputs are separable production processes. While the assumption seems reasonable for research and undergraduate teaching, it is less promising for research and graduate education. To an unknown extent these are jointly produced but for practical reasons we set this complication to one side. First, undergraduate teaching dominates most universities and this conforms to the assumption of separability. Second, statistics of teaching *expenditures* by universities do not distinguish undergraduate and graduate students. Estimated teaching faculty exceeds the number of undergraduate teachers. The result is a downward bias in undergraduate teaching productivity. Third, the proportion of graduate teaching in all teaching is higher in universities of the first rank. Omitting graduate teaching would bias teaching productivity comparisons

[5] We rely on labor productivity for the usual reason in productivity studies, that we lack data on physical capital stocks which would give us indices of total factor productivity.

between schools. A related reason for including graduate students is that top U.S. research universities have increasingly emphasized graduate teaching. Omitting graduate education would under-estimate the growth of teaching productivity. So while research and graduate education have joint production aspects, there are reasons for treating the two as separable.

We therefore use the following indexes of labor productivity in research and teaching:

$$LP_{jit} = \frac{X_{jit}}{L_{jit}}. \qquad j = R, I \tag{1}$$

Output and faculty form the numerator and denominator of (1). Subscript $j = R, I$ stands for research (R) and instruction (I), subscript i indexes universities, and t stands for time.

B. Decomposition of Productivity Growth

Section IV uses a shift-share analysis to decompose research and teaching productivity growth into within, between, and covariance components[6]. We apply this decomposition to the explanation of productivity growth in universities and groups of public and private universities.

To simplify notation we drop subscript $j = R, I$ and let LP stand for either research or teaching. Also let LP_t represent be weighted average of productivity across universities and let LP_{it} stand for productivity of university i. Finally let $s_{it} = Q_{it} / \sum_{i=1}^{N} Q_{it}$ be the share of university i in total output $\sum_{i=1}^{N} Q_{it}$. The share variable serves as a weight in the decomposition.

After some algebra, which is shown in Part A. of the Appendix, we reach

$$\Delta LP_t = LP_t - LP_{t-1} = \underbrace{\sum_i s_{it-1} \Delta LP_{it}}_{\text{Within-University}} + \underbrace{\sum_i \Delta s_{it} \Delta LP_{it}}_{\text{Covariance}} + \underbrace{\sum_i \Delta s_{it} \left(LP_{it-1} - LP_{t-1} \right)}_{\text{Between-University}} \tag{2}$$

The change in aggregate productivity consists of three terms. The first is the sum of changes in productivity within universities weighted by their share in output. This is the within-university

[6] See for example, Foster, Krizan, and Haltiwanger (2001).

component. The second is the covariance of changes in shares with changes in productivity. It answers the question: is growth in share positively or negatively associated with productivity growth? The third term is the between-university component. It is the sum of changes in shares times the difference between individual and average productivity. This captures whether more efficient universities on average gain or lose share.

Equation (2) applies to individual universities, but we are interested besides in groups of private and public universities. Part B. of the Appendix shows that

$$(3)\qquad \Delta \mathrm{LP}_{\mathrm{t}} = \underbrace{\left[\alpha_{t-1} \bullet \Delta LP_t^A + (1-\alpha_{t-1}) \bullet \Delta LP_t^B\right]}_{\text{Within-Group}} + \underbrace{\Delta\alpha_t \bullet (\Delta LP_t^A - \Delta LP_t^B)}_{\text{Covariance}} + \underbrace{\Delta\alpha_t \bullet (LP_{t-1}^A - LP_{t-1}^B)}_{\text{Between-Group}}$$

The first term is the within-group component. It is the average across the two groups of growth in productivity within each group using within-group average productivity growth. The second is the covariance component: growth in group A's share times the gap between growth in its productivity and group B's. The third term is the between-group component: the increase in group A's share times the difference in its initial productivity and that of group B. We use (2) and (3) to decompose productivity growth in higher education in Section IV.

C. Productivity Regressions

Section V undertakes regression analysis of labor productivity. For this purpose, as noted, productivity is derived from separable production functions for research and teaching. We assume that labor productivity in research takes an almost Cobb-Douglas form:

$$(4)\qquad \begin{aligned} LP_{Rit} = Q_{Rit} / L_{Rit} &= \frac{(A_{Rit} L_{Rit})^{\alpha_R} \left(\delta_R K_{it}^{NF} + K_{it}^{F} \right)^{\beta_R} e^{\gamma_R t + u_{Rit}}}{L_{Rit}}, \\ &= A_{Rit}^{\alpha_R} L_{Rit}^{\alpha_R - 1} \left(\delta_R K_{it}^{NF} + K_{it}^{F} \right)^{\beta_R} e^{\gamma_R t + u_{Rit}} \end{aligned}$$

The term A_{Rit} captures productivity-augmenting features of universities[7]. We decompose R&D of a university (K_{Rit}) into the nonfederal stock (K_{Rit}^{NF}), on which we allow a discount or premium δ_R and the federal stock (K_{Rit}^{F}). Thus the "effective" R&D stock is $K_{Rit} = \delta_R K_{Rit}^{NF} + K_{Rit}^{F}$.[8] Also included in (4) are time trend t and u_{Rit}, the error term in research productivity. Besides δ_R, the parameters include α_R, the output elasticity of labor; β_R, the output elasticity of R&D stock; and γ_R, the coefficient of time trend.

One determinant of A_{Rit} is the dummy indicator of public or private control C_i. This affects productivity through governance and selectivity. Endowment E_{it} is used to hire star faculty and buy back time, so we expect it to increase productivity. And both post-doctoral and graduate students M_{it} and G_{it} could augment faculty time. Research labor-augmentation follows the constant-elasticity function,

$$A_{Rit} = B_R e^{\eta_{RC} C_i} E_{it}^{\eta_{RE}} M_{it}^{\eta_{RM}} G_{it}^{\eta_{RG}} ,$$

Inserting this into (4), rearranging, and taking logarithms we reach the nonlinear regression

$$\begin{aligned} \text{(5)} \qquad & \ln(Q_{Rit}/L_{Rit}) = \alpha_R \ln(B_R) + \gamma_R t + \alpha_R \eta_{RC} C_i + \alpha_R \eta_{RE} \ln(E_{it}/L_{Rit-1}) + \\ & \alpha_R \eta_{RM} \ln(M_{it}/L_{Rit-1}) + \alpha_R \eta_{RG} \ln(G_{it}/L_{Rit-1}) + \beta_R \ln\left[(\delta_R K_{Rit}^{NF} + K_{Rit}^{F})/L_{Rit-1}\right] + \\ & [\alpha_R(1+\eta_{RE}+\eta_{RM}+\eta_{RG}) + \beta_R - 1]\ln(L_{Rit-1}) + u_{Rit} \end{aligned}$$

Section V reports estimates of (5). When constant returns to scale hold the coefficient on the logarithm of L_{Rit} vanishes. Otherwise its sign captures the direction of divergence from constant

[7] The (almost) Cobb-Douglas assumption means that Hicks-neutral shifts cannot be distinguished from factor augmentation. For convenience we treat all shifts as labor augmenting.
[8] This functional form allows a direct comparison between the effects of a dollar of non-federal and federal R&D stock. As far as we are aware, use of this device appears first in Griliches (1986), who used it to distinguish the effects of basic and applied research on firm productivity.

returns[9]. Notice that we lag L_{Rit} on the right by one year to limit division error bias.

Teaching productivity can be similarly modeled. Assuming a Cobb-Douglas production function for baccalaureate and graduate degrees, we obtain the following specification for teaching productivity

$$(6) \qquad LP_{Iit} = Q_{Iit} / L_{Iit} = \frac{(A_{Iit} L_{Iit})^{\alpha_I} S_{it}^{\beta_I} e^{\gamma_I t + u_{Iit}}}{L_{Iit}} = A_{Iit}^{\alpha_I} L_{Iit}^{\alpha_I - 1} S_{it}^{\beta_I} e^{\gamma_I t + u_{Iit}} .$$

Labor augmentation A_{Iit} depends on teaching skill and other aspects of teaching. Included are enrollments or stocks of students in residence S_{it}; time trend t; and u_{Iit}, the error term in teaching productivity. Parameters are α_I, the output elasticity of labor, β_I, the output elasticity of R&D stock, and γ_I, the coefficient of time trend.

Determinants of instructional labor-augmentation A_{Iit} again include public or private control C_i. A second determinant, in public universities, is state teaching appropriations per teacher T_{it}. This could be destined for the reduction of class size. If so we expect it to reduce degrees per teacher. Alternatively, state appropriations could alter the composition of education in favor of graduate education. But in addition T_{it} could increase the quality of education. And third, graduate students G_{it} per teacher could substitute for faculty in undergraduate teaching. Thus instructional labor-augmentation is represented by the constant-elasticity function,

$$A_{Iit} = B_I e^{\eta_{IC} C_i} T_{it}^{\eta_{IT}} G_{it}^{\eta_{IG}} .$$

Next insert A_{Iit} into (6) and take logarithms:

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[9] Adams and Griliches (1998) regress the logarithm of research output on the logarithm of R&D stock. They find that the specification exhibited diminishing returns at the university-field level and constant returns at the field level. But they did not examine labor productivity, because the data were not available.

$$(7) \quad \begin{aligned} &\ln(Q_{Iit}/L_{Iit}) = \alpha_I \ln(B_I) + \gamma_I t + \alpha_I \eta_{IC} C_i + \alpha_I \eta_{IT} \ln(T_{it}/L_{Iit-1}) + \\ &\alpha_I \eta_{IG} \ln(G_{it}/L_{Iit-1}) + \beta_I \ln(S_{it}/L_{Iit-1}) + [\alpha_I(1+\eta_{IT}+\eta_{IG}) + \beta_I - 1]\ln(L_{Iit-1}) + u_{Iit} \end{aligned}$$

We also include the logarithm of R&D stock in some of the graduate student equations, using the same functional form $\beta_I \ln(K_{Rit}) = \beta_I \ln\left(\delta_I K_{Rit}^{NF} + K_{Rit}^{F}\right)$, as in (4). Section IV reports estimates of (7). If constant returns holds the coefficient on L_{Iit} disappears; otherwise its sign captures the divergence from constant returns. As before, we lag L_{Iit} to limit division error bias.

III. Description of the Data

A. Database of Universities

This study is based on 110 universities that account for most academic research in the United States. The primary data sources that we use are the Institute for Scientific Information (ISI) for research outputs, the Integrated Postsecondary Education Data System (IPEDS) data from the National Center for Education Statistics (NCES) for finances, faculty, salaries, and degrees; and the National Science Foundation (NSF) CASPAR database for academic R&D and graduate students. Since data are missing for eight universities this study examines 102 schools. Allowing for lags we observe universities during 1982-1999. Thus, before missing values are removed, the data form a panel of 1,836 observations (18 years times 102 universities)[10].

Included in the panel are faculty counts, research and teaching expenditures, research outputs consisting of papers and citations, and teaching outputs consisting of baccalaureate and graduate degrees. We use the expenditure data to allocate faculty between research and teaching. These data yield labor productivity statistics in research and teaching. In addition we construct R&D stocks, endowment, stocks of graduate students, undergraduate enrollments, and indicators of

[10] Since research and teaching faculty are lagged one year on the right of (5) and (7), the 1981 data are excluded from the regressions.

public-private control[11]. The rest of this section describes the variables and calculations that we have performed using them.

B. Faculty Statistics

The data include estimates of faculty counts by university. We use tenure track and non-tenure track faculty counts from the National Center for Education Statistics' (NCES) Faculty Salary Survey, available through the Integrated Postsecondary Education System (IPEDS). Figure 1 shows tenure track and non-tenure track faculty over time. Non-tenure track faculty grow at a slightly faster rate than tenure track faculty, but not by enough to change the non-tenure track share, which remains at nine percent throughout the period[12].

Since faculty engages in research and teaching and these tend to be competing uses of time, we would like to obtain faculty-equivalents in these activities. If these were mutually exclusive production functions for research and teaching would be separable. This assumption is not as reasonable for graduate education, where teaching and research are to an extent jointly produced[13]. But as noted in Section II, it is necessary to tolerate some inaccuracy in the allocation of faculty to research and teaching. The data on teaching expenditures do not distinguish undergraduates from graduates and removing graduate education as an output biases the contributions of different universities.

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[11] R&D is over-counted because of transfers between universities. Such transfers should be deducted from the R&D of sending universities and added to the R&D of receiving universities. But this is not the current practice.

[12] National Science Foundation data show that the share of part-time faculty during 1981-1999 rises from 19 percent to 28 percent in research universities (National Science Board (2004), Volume 2, Table 5-17). We studied the use of part-time faculty using the biennial NCES Fall Staff Surveys from 1987 to 1997. Leaving aside graduate assistants we find that the 34 privates use a higher proportion of part-time faculty than the 68 publics. However, the part-time proportion grows faster, by 24 percent versus 10 percent. This suggests that the Salary Survey may understate relative faculty growth in public universities. But the Fall Staff Survey data are rather noisy; and they fail to classify graduate assistants by teaching and research function. The evidence presented in Table 9 below suggests that graduate students are an important substitute for faculty in public universities.

[13] Modern graduate education is often credited to the 19th century chemist Justus von Liebig, who learned how to combine graduate teaching with laboratory research. See the entry on von Liebig in the Encyclopedia Britannica and Mokyr (2002).

Thus we employ research and teaching expenditures to separate faculty into research and teaching components. Note that these categories exclude administration, sports, and auxiliary enterprises such as food and dormitory services, hospitals, and student organizations. This seems correct since the primary activities of faculty are teaching and research. Notice also that research expenditures $REXP_{it}$ include separately budgeted expenditures that are internal and external to the university. Instructional expenditures $IEXP_{it}$ include expenditures for credit and non-credit instruction. This includes all instruction: academic, occupational, vocational, special session, community, and remedial and tutorial instruction. Also included are research and public service that are not separately budgeted.

By this account the separation of research and teaching is imperfect. But as an assumption, it is clearly an improvement on perfect multi-tasking. That assumption argues that faculty members *simultaneously* teach and perform research. We replace it with a better approximation, that the proportion of research faculty equals the proportion of research expenditures in both research and teaching expenditures $REXP_{it}/(REXP_{it} + IEXP_{it})$. Research and teaching faculty L_{Rit} and L_{Iit} in university i at time t are to a first approximation:

$$
\begin{aligned}
L_{Rit} &= \frac{REXP_{it}}{REXP_{it} + IEXP_{it}} \times L_{it} \\
L_{Iit} &= L_{it} - L_{Rit}
\end{aligned}
\quad (8)
$$

In (8) L_{it} is total faculty in university i at time t. L_{Rit} and L_{Iit} are denominators of labor productivity in research and teaching in equations (1), (4), and (6). There is however, a bias in this, which suggests that researchers are over-estimated and teachers under-estimated. Because the research skill price exceeds that of teaching, research expenditures buy fewer researchers and teaching expenditures buy more teachers than (9) would suggest. But since we know rather little about the research premium we cannot correct this bias[14].

Figure 2 charts the course of the expenditure proportion $REXP_{it} / (REXP_{it} + IEXP_{it})$. For all universities the curve's fish-hook shape reflects the decline in research funding from 1981-1983 and its subsequent recovery and expansion. But the overall curve conceals differences between public and private universities. In both cases the expenditure share declines through 1983, but afterwards the pattern differs. The research share in private schools recovers to 0.38 in 1988 but then declines. This is consistent with reductions in overhead rates for private schools in the late 1980s (Ehrenberg, 2003). The overall pattern in private universities is one of decline, from 0.41 in 1981 to 0.36 in 1999. In contrast, the research share in public universities rises from 0.33 in 1983 to 0.40 in 1999 and the overall pattern is one of increase.

Table 1 reports means and growth rates of faculty, the research expenditure proportion, and researchers and teachers. It does so for all, public, and private universities. Universities employ an average of 1,048 faculty. The research expenditure proportion is 38 percent and an estimated 381 faculty are engaged do research while 667 teach. Public universities employ 1,218 faculty of which 444 are researchers and 774 teachers. Employment in private schools is 703, of which 252 are researchers and 451 teachers.

Table 1 also presents growth rates. Researchers grow faster than teachers by 1.4 percent a year versus 0.3 percent. Thus research-intensity of faculty is growing. Growth of researchers is faster in public universities, while growth in teachers is faster in private universities[15].

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[14] Let $f = REXP / (REXP + IEXP)$ as above, and let $\rho = (w_R - w_I) / w_I > 0$, where w_R =research wage and w_I =teaching wage and let n =measured total faculty. Then it can be shown that the true number of researchers is $n^*_R = \dfrac{f}{f + (1-f)(1+\rho)} n$ and the true number of teachers is $n^*_I = \dfrac{(1-f)(1+\rho)}{f + (1-f)(1+\rho)} n$. But unfortunately the value of ρ is unknown, including its variation by university.

Figures 3 and 4 are graphs of research and teaching faculty. To concentrate on cumulative growth and facilitate comparison we normalize each time series by its 1981 value. Figure 3 shows that research faculty rise by almost 30 percent in the publics but by less than 15 percent in the privates. Figure 4 reveal that teachers grow by more than 30 percent in the privates but decline slightly in the publics. For all universities cumulative growth in researchers is 25 percent by 1999 (Figure 3) but only five percent for teachers (Figure 4). This suggests that the mix of faculty in top U.S. universities is becoming more research-oriented.

C. Research and Teaching Outputs

To calculate labor productivity in research and teaching we require output measures. We treat papers and citations as research outputs, comparable with patent statistics in industry. The articles derive from agriculture, astronomy, biology, chemistry, computer science, earth sciences, economics and business, engineering, mathematics and statistics, medicine, physics, and psychology. These fields account for most research carried on in universities. The universities publish 2.4 million papers during 1981-1999 and the papers receive 18.8 million citations. For each paper we calculate the fraction that a given university contributes. If two schools are listed each is assigned half of the paper, if three are listed each is assigned one-third, and so on. Citations received are similarly assigned and in this way we limit the problem of multiple counting of research output. The fractions are summed across fields by year to arrive at fractional paper-equivalents of a university per year. Fractional citations are similarly summed, and the citations are accumulated over the first five years since publication, yielding a five-year window on citations received. This right-truncates the citations. Also the five-year window cuts

[15] Since research expenditures that are not separately budgeted are recorded as instructional expense, the figures for instruction may include cross-subsidization of research by teaching.

off citations in 1995, the last year for which a complete record exists. Despite this the five-year window standardizes citations received and provides a quality dimension for research output.

Baccalaureate and graduate degrees are currently our indicators of teaching output. At the present time we lack a quality indicator such as cost or forward value of a degree[16]. The data are taken from NCES-IPEDS degree surveys.

The upper half of Table 2 reports mean research output consisting of papers and five-year citations, and teaching output consisting of baccalaureate and graduate degrees. As before, we report data for all, public, and private universities. Universities publish 1,183 papers per year: the papers account for 4,948 citations over their first five years. Private universities publish slightly more total papers and public universities slightly less, but private schools have a decided advantage in citations (Adams and Griliches, 1998), which probably signals differences in faculty quality as reflected in salary (Ehrenberg, 2003).

Universities produce 3,010 baccalaureate degrees and 1,747 graduate degrees per year. Reflecting their size and specialization in undergraduate education, public universities produce 3,795 baccalaureate degrees and 1,721 graduate degrees. Private universities produce 1,417 baccalaureate degrees and 1,758 graduate degrees; they specialize in graduate education.

D. Labor Productivity in Research and Teaching

The lower half of Table 2 reports means of productivity by type. The data show an 85 percent advantage of private universities in papers (7.4 papers versus 2.6 papers per faculty), and an almost 3-to-1 advantage in citations (20.4 citations versus 7.4 citations per researcher)[17].

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[16] One idea is to use National Association of Colleges and Employers (NACE) data on starting salaries by major, but these are not available to academic researchers.

[17] Means weighted by size of research faculty. Equally weighted means for public and private institutions are 3.8 and 4.9 papers per researcher, and 17.4 and 25.3 five-year citations per researcher. We prefer weighted means, which give larger universities more weight and offer a clearer picture of overall research productivity.

In Table 2 total degrees per teacher are similar across university type. Any differences show up in undergraduate and graduate productivity[18]. Indeed the total degree gap is small considering the concentration of private schools on costly graduate education. The smaller output of undergraduate degrees per faculty in these institutions again indicates their specialization in graduate education.

Figures 5 and 6 are graphs of research productivity over time. Again the series are normalized by 1981 values. All the series on papers per researcher in Figure 5 grow through 1995 and flatten afterwards. Private universities grow faster, with the divergence taking place during 1981-1995. By 1999 papers per research faculty grow by 20 percent in public universities but by 40 percent in public universities. Figure 6 reports citations received per faculty. The data series end in 1995 given the five-year window on citations. Again a gap opens up between privates and publics during 1981-1995. By 1995 citations per researcher in public universities grow by 80 per cent but by 220 percent in private universities.

Table 3 provides more evidence on the increasing productivity gap between public and private universities. Annual growth in papers is 1.4 percent in all institutions and growth in citations is 6.7 percent. Comparable figures in public universities are 1.2 percent (papers) and 6.2 percent (citations). Productivity growth in private universities equals 2.2 percent (papers) and 8.6 percent (citations).

The bottom half of the table shows growth in teaching productivity in all universities of about one percent a year. The data show a decline in teaching productivity in private universities

[18] Since the data do not allow us to distinguish undergraduate teachers from graduate teachers, we are double-counting teachers in computing teaching productivity. Thus, it is not all clear that fewer undergraduate degrees are produced per undergraduate teacher in private schools, or that fewer graduate degrees are produced per graduate teacher in public schools.

of -0.6 to -0.1 percent, compared with a rise of 1.2 to 1.4 percent in public universities. But again these measurements lack a quality dimension.

Trends in baccalaureate and graduate degrees per teacher are shown in Figures 7 and 8. The figures show that all the growth in teaching productivity occurs in public universities. Comparing these with Figures 6 and 7 we see that as measured, productivity growth is faster in research than teaching.

E. Other Data

We collected several other variables, including faculty salary, academic R&D stocks, endowment, and state teaching appropriations, all expressed in thousands of 1992 dollars. In addition we collected lagged stocks of graduate students from the NSF-CASPAR database.

Table 4 reports means of faculty compensation, consisting of wages plus fringe benefits, by faculty rank and university type. Mean compensation averages 65 thousand dollars of 1992. Compensation is higher in private universities, especially at the full professor level, so that the wage trajectory is much steeper in these universities. Figure 9 shows that compensation also rises at a faster rate in private universities. Both patterns are familiar, but what is not as well known is how closely the public-private wage differential tracks the differential in public-private research productivity (but not teaching productivity). This advantage of private universities is of course related to their financial resources.

Past R&D funding contributes to current research output and it also indicates research excellence. For both reasons it is correlated with research productivity. R&D stock is the lagged stock of research funding received over the previous eight years, depreciated at 15 percent per year, and expressed in thousands of 1992 dollars. R&D pertains to the same fields of science and schools that yield the research output statistics[19]. The source of the R&D data is the NSF-CASPAR database.

We divide the R&D stock into federal and nonfederal components. This is a likely factor in research productivity because nonfederal money could be less subject to competitive pressures than federal grants and because it may consist of contracts that provide information and advice rather than publications[20]. Figure 10 show that nonfederal R&D contributes 20 percent of the private university stock but 40 percent of the public university stock. The share of nonfederal R&D grows relative to the federal stock and is 19 percent higher by 1999.

Endowment is used to attract highly skilled faculty and to support research. For both reasons, endowment per faculty should increase research productivity. Endowment could also reduce size of classes or support students, although we fail to find evidence for this. State appropriations could reduce class size and degrees per faculty member but they could also expand graduate programs. These data derive from NCES-IPEDS surveys.

The lagged stock of graduate students helps to produce research and undergraduate teaching. It should increase research and teaching productivity, but besides this it is an output (Adams and Griliches, 1998). The graduate student data are drawn from the NSF-CASPAR database for the 12 sciences in this study. Also taken from this source is the stock of post-doctoral students, another input into research.

[19] The 12 fields are agriculture, astronomy, biology, chemistry, computer science, earth sciences, economics and business, engineering, mathematics and statistics, medicine, physics, and psychology.
[20] It is for this reason that we think that recent findings (De Figueiredo and Silverman, 2002) that 5-6 percent of federal R&D dollars are earmarked and a source of inefficiency represent an understatement of the problem. We agree that the federal question is interesting, but we also believe that replacement of federal funds by nonfederal funds may be the larger issue.

IV. Decomposition of Aggregate Productivity Growth

Following equation (2), Table 5 reports decompositions of aggregate productivity growth in research and teaching. The table contains three panels corresponding to all, public, and private universities. The top line of each panel reports aggregate productivity growth. This is arithmetic rather than percentage growth. It is the sum of the change in productivity over all universities in a given set. By (2) the within-university, covariance, and between-university components sum to the total except for rounding error. The shares of each component in aggregate productivity growth are shown in parentheses.

The within-university component dominates. It is usually positive: the exception is a small decline in teaching productivity within private universities. The covariance term is always negative: this implies that output share grows more rapidly in universities where productivity grows more slowly. The between-university component is usually positive: output shares grow in universities whose productivity is above average. One exception to this is a slight decline in the between-university component of citations.

We would like to compare Table 5 with decompositions for the private sector. Foster, Haltiwanger and Krizan (2001) offers the closest comparison. In their findings for industry the within-establishment component is a much smaller share of productivity growth[21]. This is partly because net entry contributes to industry growth. Entry is identically zero for top universities but besides this, the covariance term is positive in industry and negative in higher education. In summary while entry and between-establishment reallocation increase private sector growth, they are either not a factor (entry) or they decrease growth in universities (covariance).

Table 6 studies growth in groups of public and private universities. The decomposition follows (3). Within-group productivity growth is positive but the covariance and between-group

[21] See Foster, Haltiwanger and Krizan (2001), P. 322, Table 8.4, line 2.

terms are negative in seven out of eight cases. The results imply that the share in research and teaching rises faster for the group whose productivity grows more slowly (covariance component), and that the share grows faster for the group whose productivity is less (between-group component). In research it is the less efficient group of public universities whose share increases, while in teaching it is the apparently less efficient group of private universities.

V. Regression Findings

The empirical work concludes with regression analysis of research and teaching productivity. Tables 7 and 8 contain findings on research productivity in public and private universities. The dependent variable in 7.1-7.3 is the logarithm of papers per research faculty. The dependent variable in 7.4-7.6 is the logarithm of five-year citations to the papers per research faculty. Equations 7.3 and 7.6 include university fixed effects while the rest exclude these effects.

Consider papers per researcher in public universities. The coefficient of time trend is negative and significant in 7.1 and 7.2 but is positive and significant in 7.3. This is consistent with the shift of research towards less productive universities. Table 5 has shown that as a result, within-university growth accounts for more than 100 percent of growth. This negative "between" effect is included in 7.1 and 7.2 but is omitted from the "within" regression 7.3.

Besides trend, the table includes the logarithm of R&D stock per researcher, and it also includes the logarithm of lagged researchers, as a check on returns to scale. The nonfederal coefficient is significantly less than that of federal R&D and it approximates zero in the citation regressions[22]. The R&D elasticity is always positive. The coefficient of lagged researchers is negative, suggesting decreasing returns to scale throughout.

[22] The negative sign on nonfederal R&D does not hit a boundary because nonfederal funds are small.

Equation 7.2 adds endowment, graduate students, and post-doctoral students to 7.1[23]. The effect of R&D stock declines but remains positive and significant. Since R&D stock supports graduate and post-doctoral students, part of its effect is mediated by these variables, which are accordingly positive and significant. In 7.2, endowment has a small positive effect. The sign and significance of lagged researchers again suggests diminishing returns.

We include fixed effects in the within-university equation 7.3, which is otherwise the same as 7.2. The elasticities of the R&D stock, graduate students, and post-doctoral students decline in the within-university dimension but remain positive and significant. Endowment is now negative and significant, which is puzzling. Diminishing returns are stronger than before.

Equations 7.4-7.6 report citation regressions whose setup follows 7.1-7.3. Compared to the earlier results trend growth is higher but consistent with Table 5 it is still higher in the “within” regression 7.6. The discount of nonfederal R&D is even greater than for papers, but this effect disappears in 7.6. The elasticity of R&D stock is higher than in the papers regressions, which suggests that part of R&D’s effect occurs through research quality. Diminishing returns to R&D continues to prevail. The contribution of post-doctoral students (but not graduate students) to research productivity remains positive and significant once fixed effects are included.

Table 8 reports similar results for private universities. Equations 8.1-8.2 and 8.4-8.5 are the “total” specifications for papers and citations. As in Table 7 the coefficient of time trend reverses sign when fixed effects are included in 8.3 and 8.6. When fixed effects are included, as in 8.3 and 8.6, the elasticity of the R&D stock declines but this coefficient remains significant. The estimate of the nonfederal coefficient is imprecise: in the papers equations 8.1 and 8.3 it is significantly less than 1.0, but in 8.2 this difference is not significant. The nonfederal effect is significantly less than zero in 8.4 and 8.5 but does not differ from 1.0 in the “within” equation

[23] To be more precise, graduate and post-doctoral students are averages of stocks over the previous three years.

8.6. Overall, as in Table 7, the nonfederal R&D coefficient is less than or equal to that of federal R&D. Endowment is consistently stronger in Table 8, implying that private universities are adept at harnessing endowment to raise their research productivity. The coefficient of post-doctoral students increases but the graduate student coefficient decreases compared with Table 7. Thus private universities rely more on post-doctoral students to produce their research.

Finally we turn to Tables 9 and 10, which contain regression findings for teaching productivity. The dependent variable in 9.1-9.3 and 10.1-10.3 is the logarithm of baccalaureate degrees per teacher. In 9.4-9.6 and 10.4-10.6 it is the logarithm of graduate degrees per teacher.

We begin with undergraduate productivity in public universities. Equation 9.1 includes time trend, the logarithm of undergraduate enrollments per teacher, and following (7) the logarithm of teachers, to test for the returns to scale to teaching[24]. Time trend is insignificant. The logarithm of enrollment is positive and significant, and its coefficient is robust in 9.3 to the inclusion of fixed effects. We would expect it to be robust given that students are inputs into their own education (Rothschild and White, 1995, Winston, 1999). The coefficient of teaching faculty is positive and significant in 9.1, suggesting increasing returns. However, when fixed effects are included in 9.3 this sign reverses. Thus, unlike research, where returns are decreasing, the evidence on returns to scale is mixed in undergraduate teaching.

Equation 9.2 includes the logarithms of graduate students, endowment, and state appropriations per teacher. Graduate students play a significant role in public undergraduate education but it is perhaps not surprising that endowment has little effect. State appropriations reduce degrees per faculty, but the interpretation of this is unclear. Equation 9.3 adds fixed effects to 9.2. Enrollment and graduate students remain important determinants of baccalaureate degrees within universities, but state appropriations drop out.

[24] To be precise, undergraduate enrollment is the average undergraduate enrollment over the previous three years.

The graduate teaching equations conclude Table 9. Equation 9.4 includes trend, graduate students, and lagged teachers. Trend is positive and significant, graduate students are a key input into their own education, and the sign of lagged teachers provides some evidence of diminishing returns. Equation 9.5 adds state appropriations per teacher. These increase output of graduate degrees, the opposite of 9.2. Together this suggests that state support substitutes graduate students for undergraduates. Since R&D hones the research skills of graduate students, equation 9.5 also includes the logarithm of the stock of R&D. The coefficient of nonfederal stock has a negative effect on graduate degrees; this is insignificant in 9.6. Federal R&D supports graduate education while nonfederal R&D does not. Equation 9.6 adds fixed effects to 9.5. Coefficients of graduate students and R&D stock remain significant, but the signs of endowment, state appropriations, and lagged teachers change. In particular, the evidence on decreasing returns in this table is fragile and conflicting. Along with the evidence on decreasing returns to research it suggests that variation in university size is primarily due to teaching.

Table 10 reports findings for private universities. Main differences from Table 9 are these. First, there is evidence for decreasing returns to undergraduate teaching in private universities. Second, unlike their role in public universities, graduate students are not a significant input for undergraduate education. As before graduate degrees do not increase with nonfederal R&D.

VI. Discussion and Conclusion

This paper finds evidence of growing allocative inefficiency in U.S. higher education. Our most compelling evidence for this claim derives from research output, which is better measured than teaching output at this time. We find that universities whose productivity grows less rapidly experience more rapid growth in research share. The allocation of research between public and private universities has also grown less efficient over time. While the share of public universities grows more rapidly their research productivity grows more slowly. On top of this the between-university component is negative: the public university share grows though their research productivity is less. One suspect that might explain this growing inefficiency is nonfederal R&D. Its more rapid growth and its much larger role in public universities fit the patterns that we observe. In support of this view, Tables 7 and 8 show that nonfederal R&D stock decreases research productivity. Whether this result is due to less competitive conditions attending nonfederal grants or whether nonfederal awards produce less research by intention, we cannot say. According to Tables 7 and 8 private university endowments also contribute to the gap in public-private research productivity.

Our findings for teaching productivity are similar, but we are less convinced by them. For starters, the quality dimension of instruction is missing. Falling class size could reflect a rising demand for quality due to growth in wealth at the top of the distribution. This indicates that families partly control the allocation of students to schools. Surely this moderates allocative inefficiency in teaching.

A deeper interpretation of the observations might instead point to the financial fortunes of public and private universities over the past quarter century. The public-private comparisons in this paper are consistent with rising teaching pressures on public universities that could well discourage more productive researchers from applying for positions. This decline in competitiveness might explain the increasing reliance, especially by state universities, on nonfederal R&D that appears to detract from research-productivity. On that interpretation, the rising allocative inefficiency of research that we uncover results from funding pressures that render state universities less competitive, and drive them to less productive funding sources.

This view of the matter implies a stunning reversal of fortune for public universities.

Starting from the Morrill Act of 1862 and the Hatch Act of 1887, state universities offered practical education in the agricultural and mechanical arts to support local industry. For more than a century this formula has achieved great successes (Huffman and Evenson, 1993; Adams, 2002). But in our own time it appears to have been less successful. This can perhaps be traced to aging of the population and to the rising mobility of students, both of which weaken the appeal of state finance of universities. If this interpretation is correct, then it suggests a different and more privatized approach to funding universities that would place greater reliance on parental finance of teaching, and federal and private foundation finance of research. In any event, some solution seems urgent if the U.S. is to retain its preeminence in higher education, and subsequently in science, technology, and innovation.

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Appendix
Productivity Decomposition

Section IV uses the shift-share analysis described in Foster, Haltiwanger, and Krizan (2001) to decompose productivity growth into within, between, and covariance components for universities. This section explains the algebra underlying equations (2) and (3) of the text.

A. Decomposition among Individual Universities

Let LP_t represent mean labor productivity across universities, LP_{it} stand for productivity of a university, and $s_{it} = Q_{it} / \sum_{i=1}^{N} Q_{it}$ represent the share of a university in total output. Then

(A.1)
$$\begin{aligned}\Delta LP_t &= LP_t - LP_{t-1} \\ &= \sum_i s_{it} LP_{it} - \sum_i s_{it-1} LP_{it-1} = \sum_i s_{it} LP_{it} - \sum_i s_{it-1} LP_{it-1} + \\ &\sum_i s_{it-1} LP_{it} - \sum_i s_{it-1} LP_{it} = \sum_i s_{it-1} \Delta LP_{it} + \sum_i s_{it} LP_{it} - \sum_i s_{it-1} LP_{it} = \\ &= \sum_i s_{it-1} \Delta LP_{it} + \sum_i s_{it} LP_{it} - \sum_i s_{it-1} LP_{it} \\ &+ \sum_i s_{it} LP_{it-1} - \sum_i s_{it} LP_{it-1} + \sum_i s_{it-1} LP_{it-1} - \sum_i s_{it-1} LP_{it-1} \\ &= \sum_i s_{it-1} \Delta LP_{it} + \sum_i \Delta s_{it} \Delta LP_{it} + \sum_i \Delta s_{it} LP_{it-1}\end{aligned}$$

To (A.1) we add the term:

(A.2) $$\sum_i \Delta s_{it} LP_{t-1}$$

(A.2) equals zero because LP_{t-1} can be factored out and the sum of the changes in shares is zero. Combining terms in the result yields equation (2) of the text:

(A.3) $$\Delta LP_t = LP_t - LP_{t-1} = \underbrace{\sum_i s_{it-1} \Delta LP_{it}}_{\text{Within-University}} + \underbrace{\sum_i \Delta s_{it} \Delta LP_{it}}_{\text{Covariance}} + \underbrace{\sum_i \Delta s_{it} \left(LP_{it-1} - LP_{t-1} \right)}_{\text{Between-University}}$$

B. Decomposition among Groups of Universities

We are also interested in contributions of groups of universities A and B to productivity growth. Let A and B exhaust the set of universities. Then aggregate labor productivity growth is

(A.4)
$$\begin{aligned}\Delta LP_t = LP_t - LP_{t-1} &= \sum_i s_{it} LP_{it} - \sum_i s_{it-1} LP_{it-1} = \\ &\left(\sum_A s_{it} LP_{it} - \sum_A s_{it-1} LP_{it-1} \right) + \left(\sum_B s_{it} LP_{it} - \sum_B s_{it-1} LP_{it-1} \right)\end{aligned}$$

Notice that the s_{it} weights do not add to 1.0 within groups. The following equation rewrites the weighted averages of labor productivities in (A.4) in terms of within-group averages:

(A.5)
$$\begin{aligned}\Delta LP_t &= \left(\alpha_t \sum_A s^A{}_{it} LP_{it} - \alpha_{t-1} \sum_A s^A{}_{it-1} LP_{it-1}\right) \\ &+ \left((1-\alpha_t)\sum_B s^B{}_{it} LP_{it} - (1-\alpha_{t-1})\sum_B s^B{}_{it-1} LP_{it-1}\right)\end{aligned}$$

The three new terms in (A.5) are:

(A.6)
$$\alpha_t = \sum_A Q_{it} \div \left(\sum_A Q_{it} + \sum_B Q_{it}\right)$$

(A.7)
$$\begin{aligned} s^A{}_{jt} &= Q_{jt} \div \left(\sum_A Q_{it}\right), \qquad j \in A \\ s^B{}_{jt} &= Q_{jt} \div \left(\sum_B Q_{it}\right), \qquad j \in B \end{aligned}$$

Factor total output from the denominator of (A.6). Then multiply and divide by the sum of output in each group using the within-group weights (A.7). As a result we can rewrite (A.5) as

(A.8)
$$\begin{aligned}\Delta LP_t &= \left(\alpha_t LP_t^A - \alpha_{t-1} LP_{t-1}^A\right) \\ &+ \left((1-\alpha_t) LP_t^B - (1-\alpha_{t-1}) LP_{t-1}^B\right)\end{aligned}$$

The top line of (A.8) is

(A.9)
$$\alpha_t LP_t^A - \alpha_{t-1} LP_{t-1}^A = \alpha_{t-1} \bullet \Delta LP_t^A + \Delta\alpha_t \bullet \Delta LP_t^A + \Delta\alpha_t \bullet LP_{t-1}^A$$

The bottom line of (A.8) equals

(A.10)
$$(1-\alpha_t) LP_t^B - (1-\alpha_{t-1}) LP_{t-1}^B = (1-\alpha_{t-1}) \bullet \Delta LP_t^B + \Delta(1-\alpha_t) \bullet \Delta LP_t^B + \Delta(1-\alpha_t) \bullet LP_{t-1}^B$$

Substitute (A.9) and (A.10) into (A.8) and combine terms using $\Delta(1-\alpha_t) = -\Delta\alpha_t$. We reach

(A.11)
$$\begin{aligned}\Delta \mathrm{LP}_t &= \underbrace{\left[\alpha_{t-1} \bullet \Delta LP_t^A + (1-\alpha_{t-1}) \bullet \Delta LP_t^B\right]}_{\text{Within-Group}} + \underbrace{\Delta\alpha_t \bullet (\Delta LP_t^A - \Delta LP_t^B)}_{\text{Covariance}} \\ &+ \underbrace{\Delta\alpha_t \bullet (LP_{t-1}^A - LP_{t-1}^B)}_{\text{Between-Group}}\end{aligned}$$

(A.11) is equation (3) of the text.

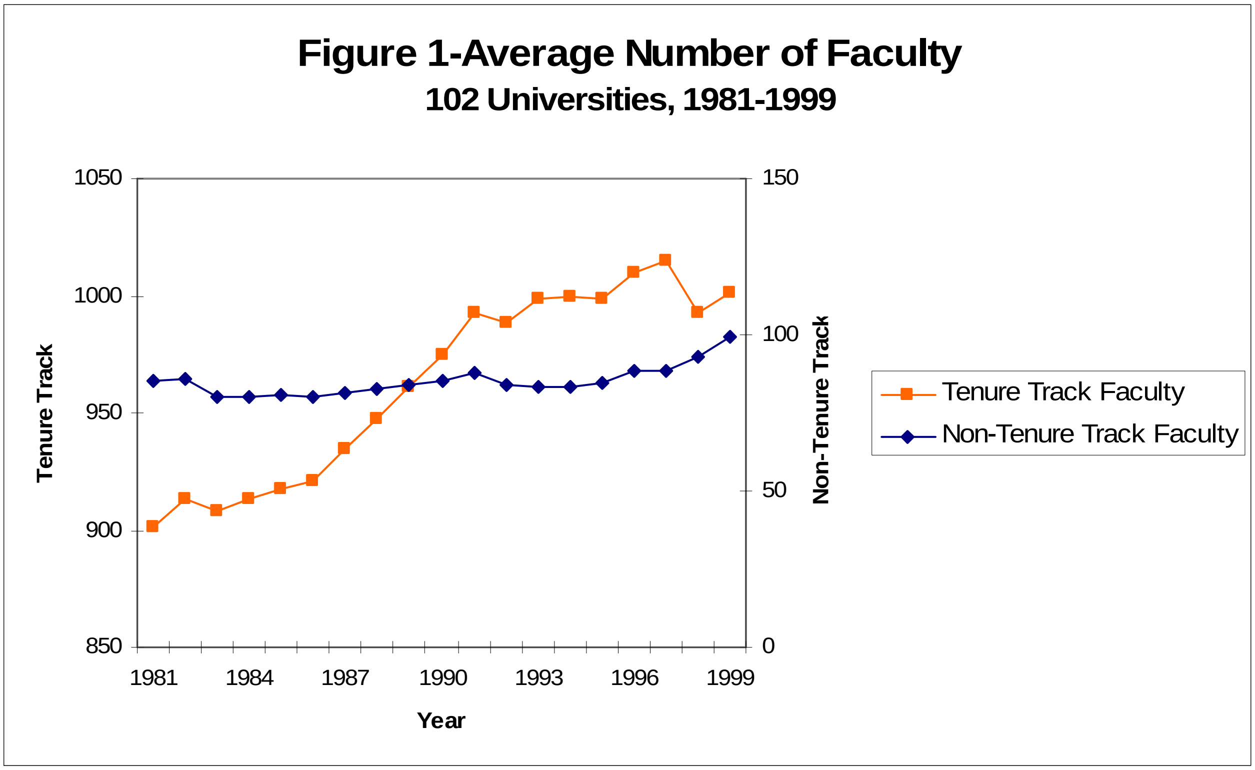

Figure 1-Average Number of Faculty
102 Universities, 1981-1999
1050
1000
950
900
850
Tenure Track
150
100
50
0
Non-Tenure Track
1981
1984
1987
1990
1993
1996
1999
Year
Tenure Track Faculty
Non-Tenure Track Faculty

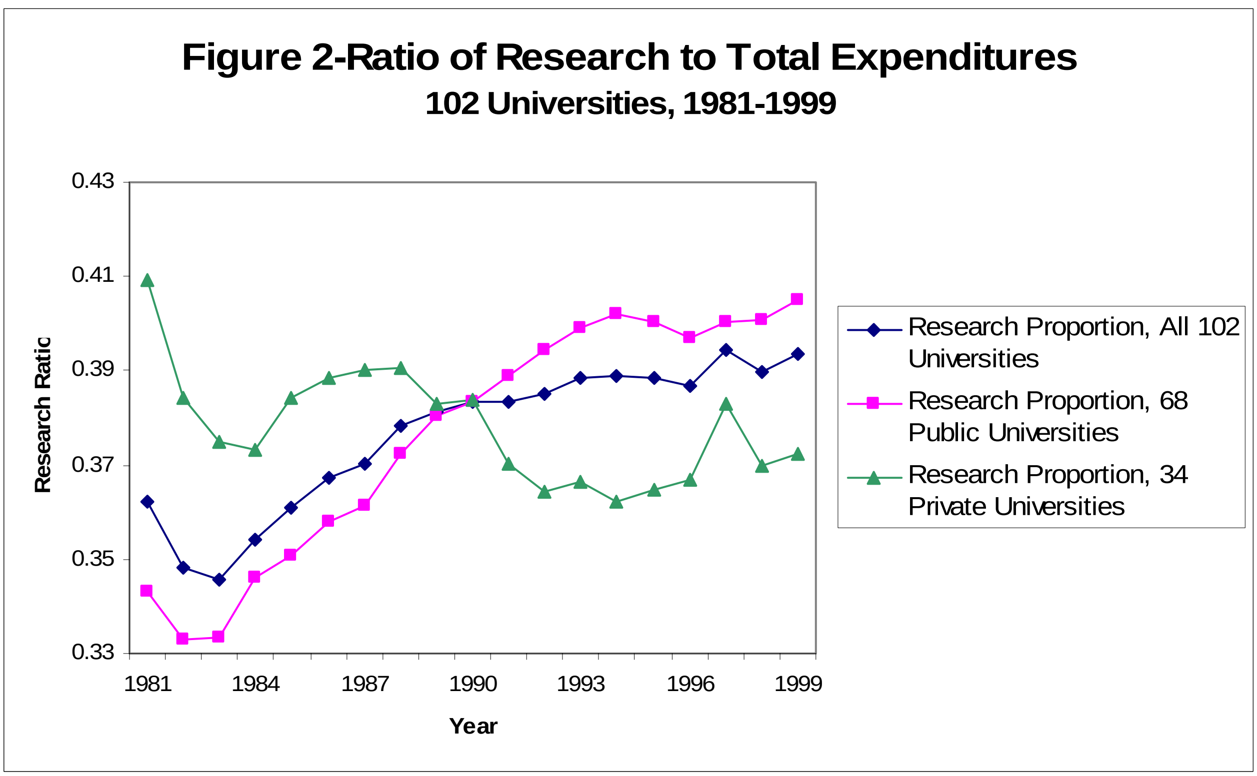

Figure 2-Ratio of Research to Total Expenditures
102 Universities, 1981-1999
0.43
0.41
0.39
0.37
0.35
0.33
Research Ratio
1981
1984
1987
1990
1993
1996
1999
Year
Research Proportion, All 102 Universities
Research Proportion, 68 Public Universities
Research Proportion, 34 Private Universities

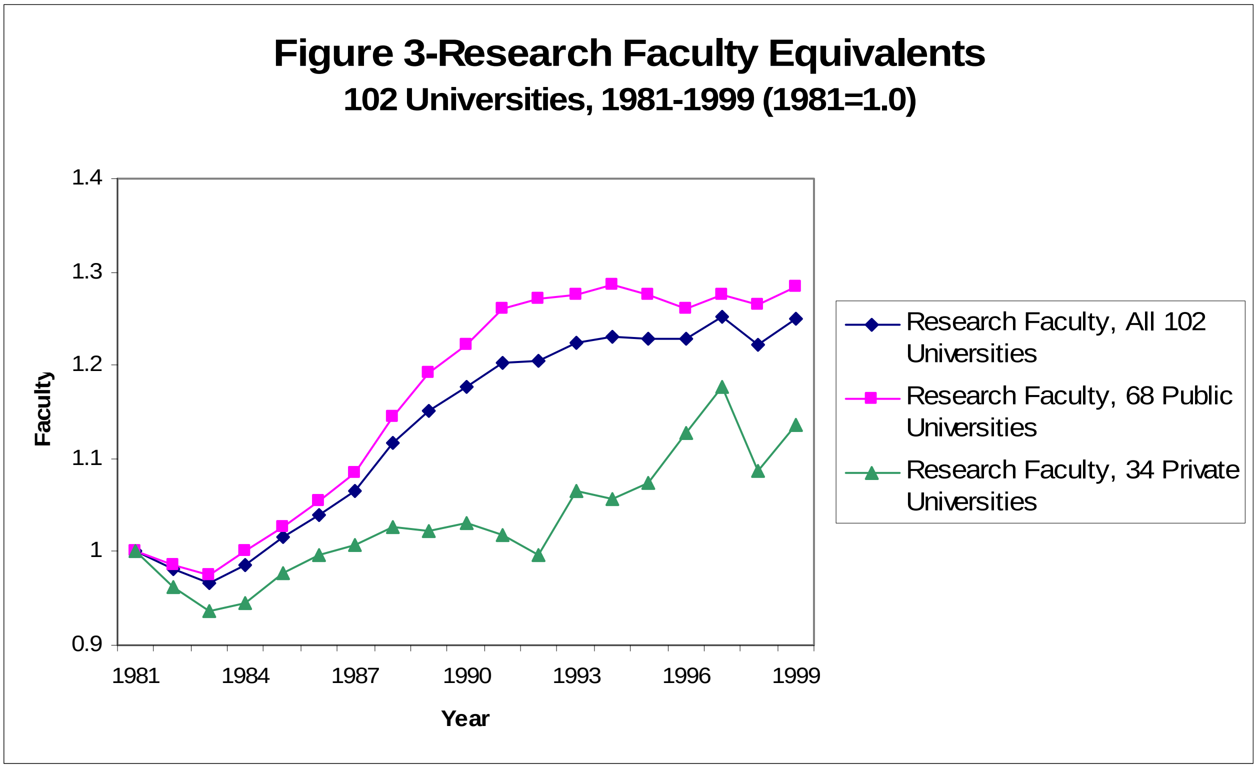
Figure 3-Research Faculty Equivalents
102 Universities, 1981-1999 (1981=1.0)
1.4
1.3
1.2
1.1
1
0.9
Faculty
1981
1984
1987
1990
1993
1996
1999
Year
Research Faculty, All 102 Universities
Research Faculty, 68 Public Universities
Research Faculty, 34 Private Universities

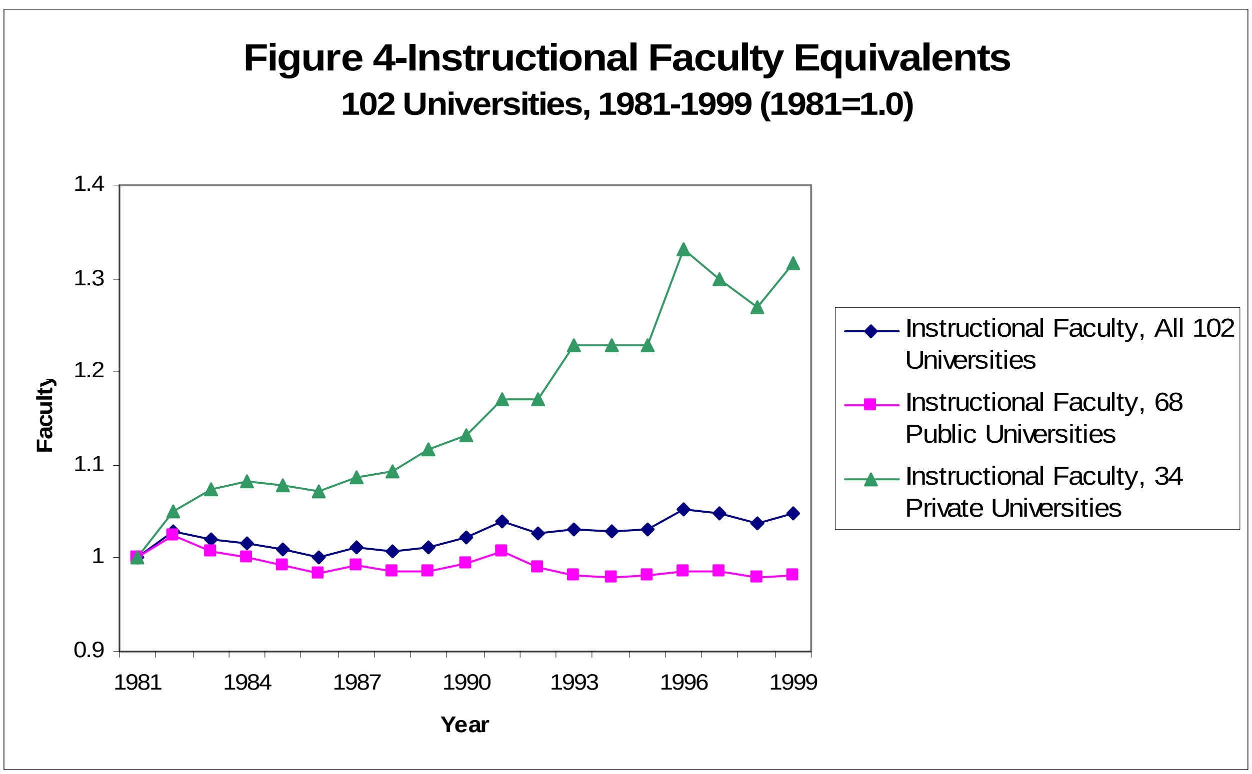
Figure 4-Instructional Faculty Equivalents
102 Universities, 1981-1999 (1981=1.0)
1.4
1.3
1.2
1.1
1
0.9
Faculty
1981
1984
1987
1990
1993
1996
1999
Year
Instructional Faculty, All 102 Universities
Instructional Faculty, 68 Public Universities
Instructional Faculty, 34 Private Universities

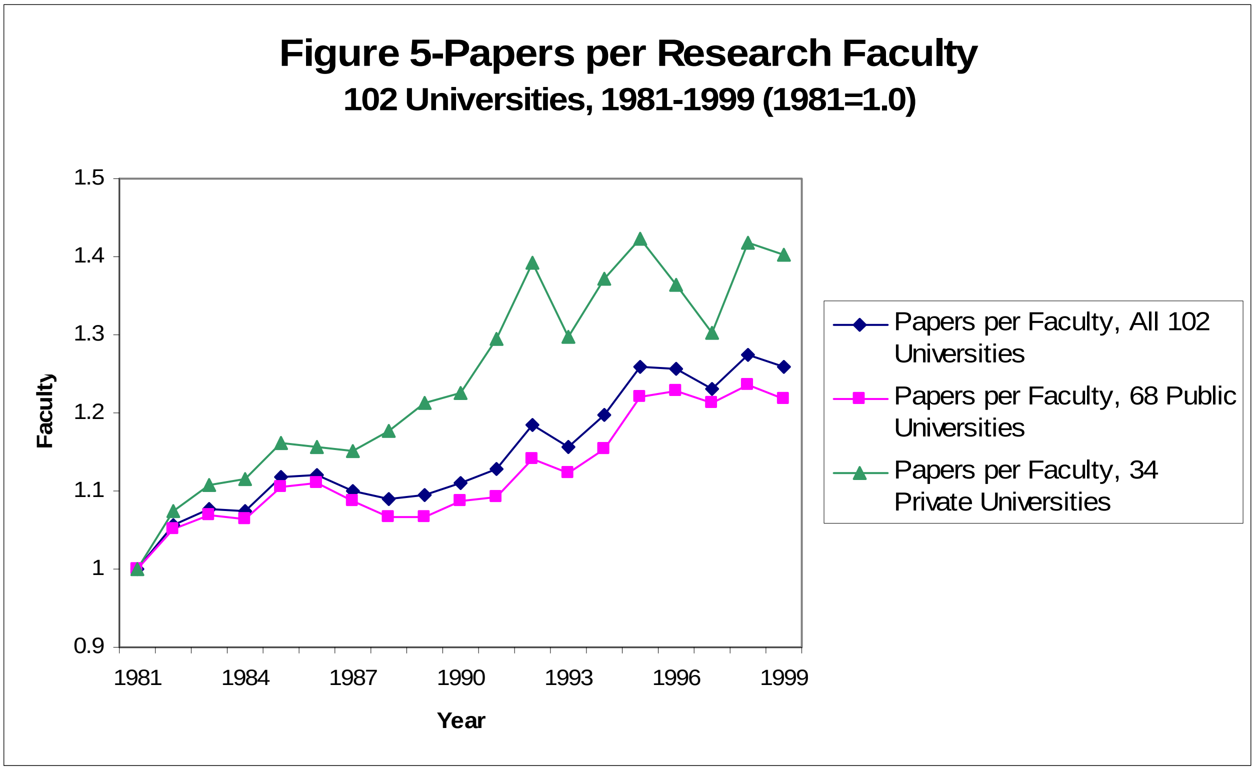
Figure 5-Papers per Research Faculty
102 Universities, 1981-1999 (1981=1.0)
1.5
1.4
1.3
1.2
1.1
1
0.9
Faculty
1981
1984
1987
1990
1993
1996
1999
Year
Papers per Faculty, All 102 Universities
Papers per Faculty, 68 Public Universities
Papers per Faculty, 34 Private Universities

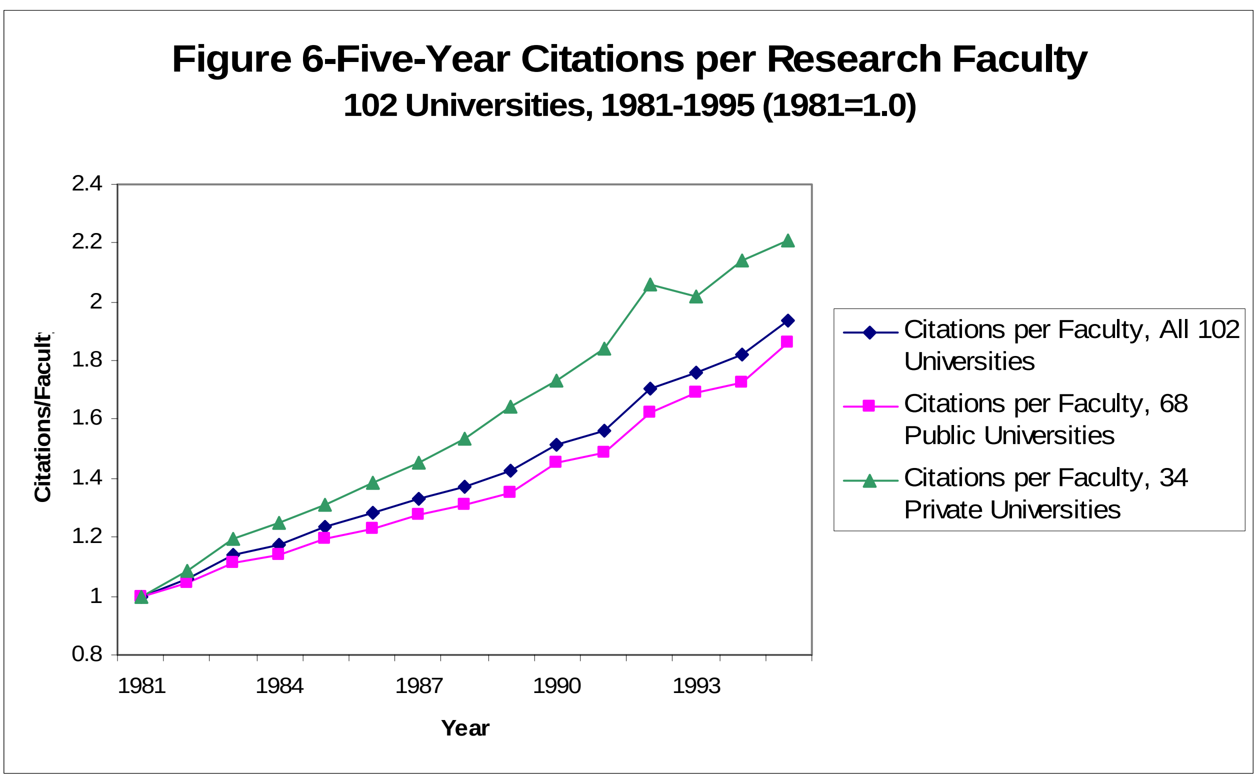
Figure 6-Five-Year Citations per Research Faculty
102 Universities, 1981-1995 (1981=1.0)
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
Citations/Facult
1981
1984
1987
1990
1993
Year
Citations per Faculty, All 102 Universities
Citations per Faculty, 68 Public Universities
Citations per Faculty, 34 Private Universities

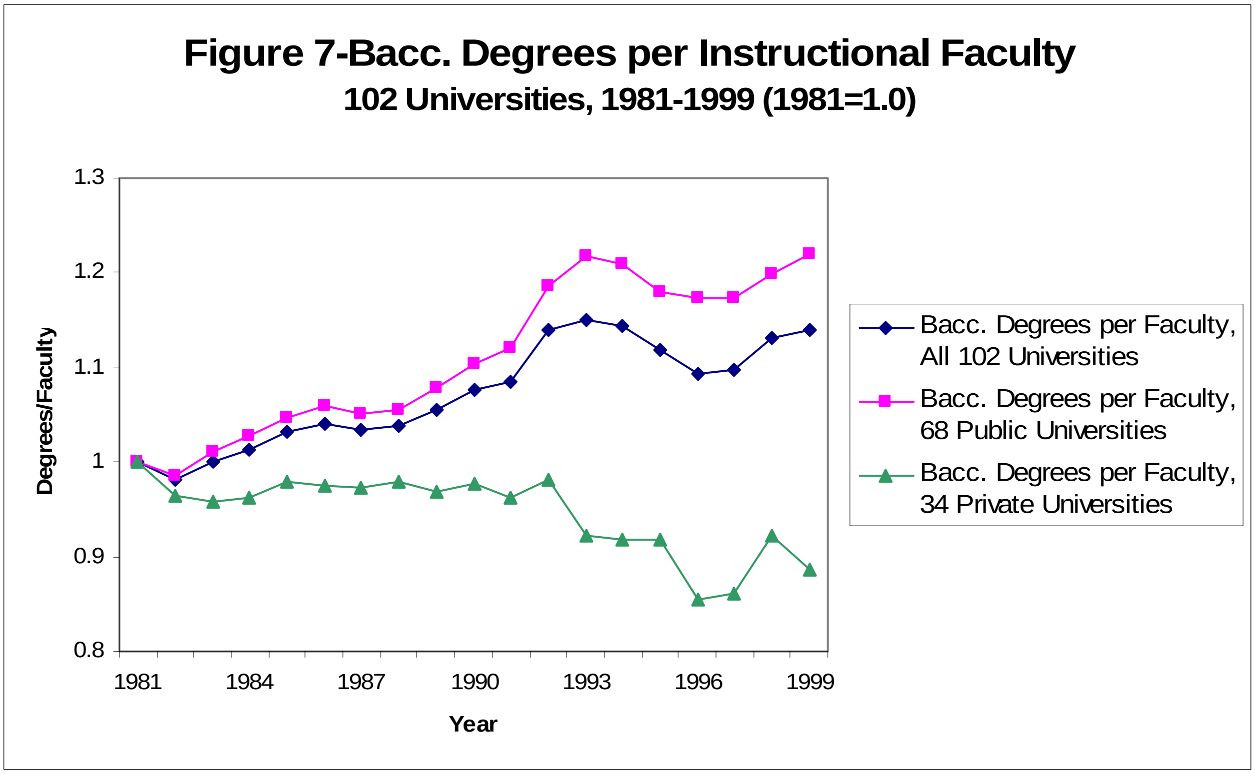
Figure 7-Bacc. Degrees per Instructional Faculty
102 Universities, 1981-1999 (1981=1.0)
Degrees/Faculty
Year
1.3
1.2
1.1
1
0.9
0.8
1981
1984
1987
1990
1993
1996
1999
Bacc. Degrees per Faculty, All 102 Universities
Bacc. Degrees per Faculty, 68 Public Universities
Bacc. Degrees per Faculty, 34 Private Universities

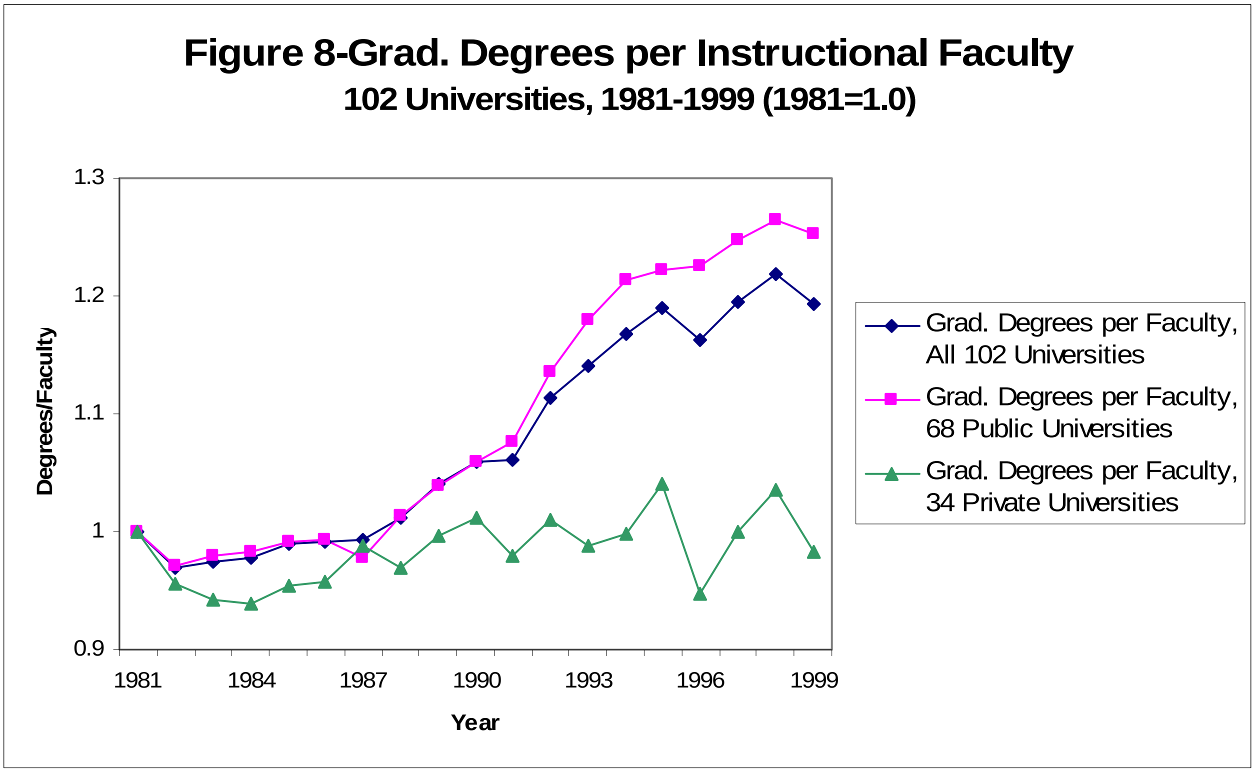
Figure 8-Grad. Degrees per Instructional Faculty
102 Universities, 1981-1999 (1981=1.0)
Degrees/Faculty
Year
1.3
1.2
1.1
1
0.9
1981
1984
1987
1990
1993
1996
1999
Grad. Degrees per Faculty, All 102 Universities
Grad. Degrees per Faculty, 68 Public Universities
Grad. Degrees per Faculty, 34 Private Universities

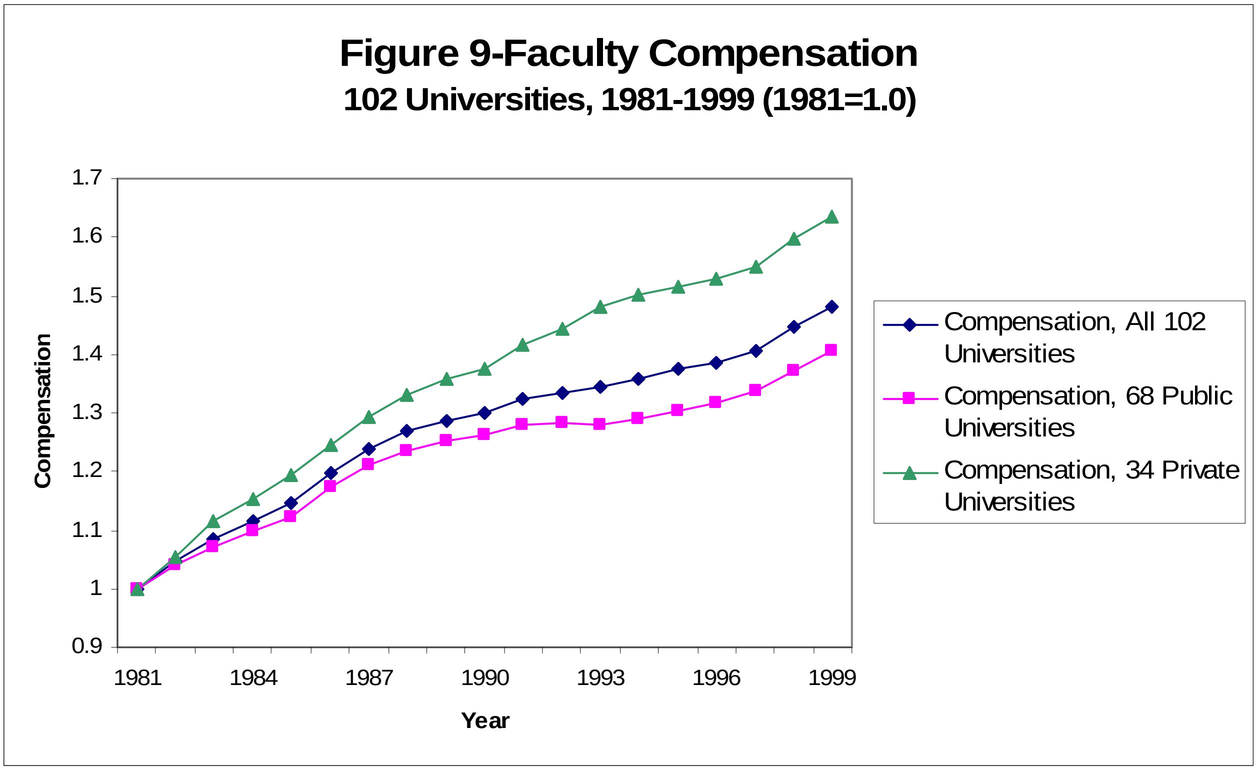
Figure 9-Faculty Compensation
102 Universities, 1981-1999 (1981=1.0)
Compensation
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
1981
1984
1987
1990
1993
1996
1999
Year
Compensation, All 102 Universities
Compensation, 68 Public Universities
Compensation, 34 Private Universities

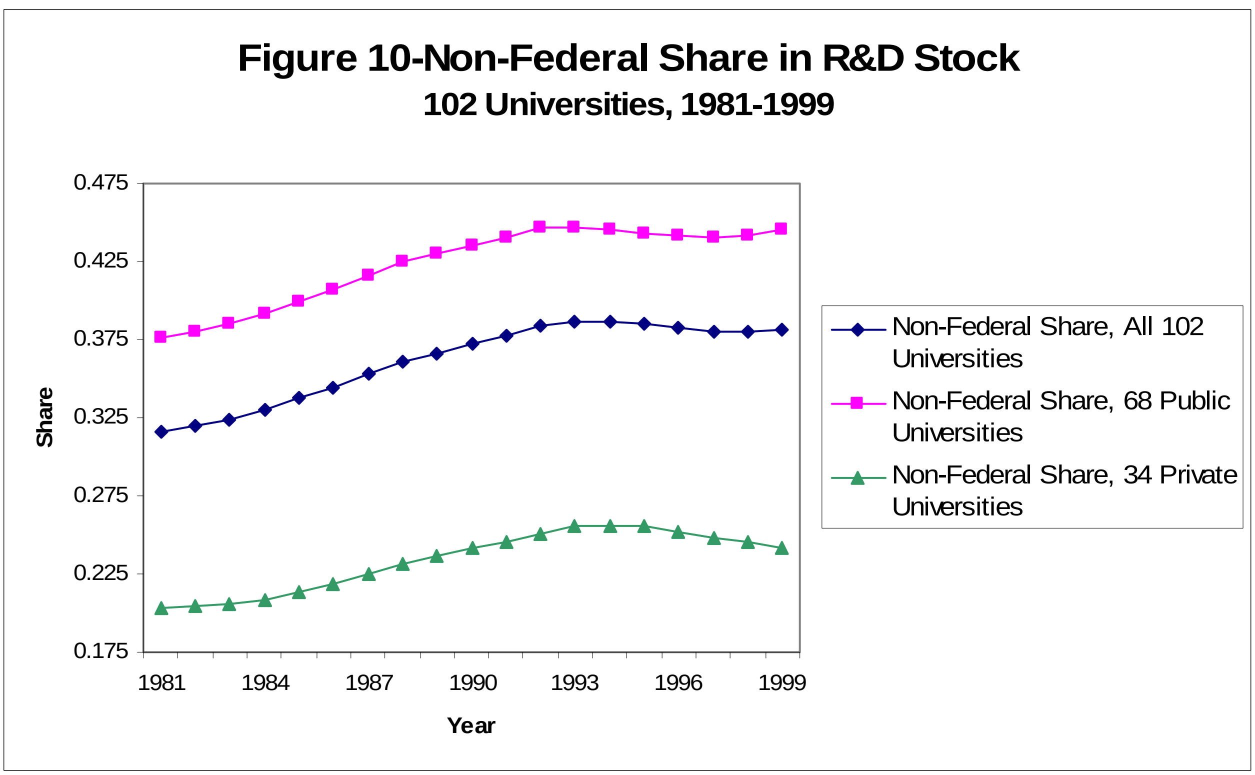
Figure 10-Non-Federal Share in R&D Stock
102 Universities, 1981-1999
Share
0.475
0.425
0.375
0.325
0.275
0.225
0.175
1981
1984
1987
1990
1993
1996
1999
Year
Non-Federal Share, All 102 Universities
Non-Federal Share, 68 Public Universities
Non-Federal Share, 34 Private Universities

Table 1
Faculty by Research and Teaching Function,
Public and Private Universities, 1981-1999

Faculty Indicator	University Classification		
	All	Public	Private
Means			
Tenure Track + Non-Tenure Track Faculty	1,048	1,218	703
Research Expenditure Proportion	0.379	0.381	0.376
Research Faculty-Equivalents	381	444	252
Instructional Faculty-Equivalents	667	774	451
Annual Percentage Growth Rates			
Tenure Track + Non-Tenure Track Faculty	0.6	0.4	1.4
Research Expenditure Proportion	0.5	1.0	-0.5
Research Faculty-Equivalents	1.4	1.6	0.8
Instructional Faculty-Equivalents	0.3	-0.1	1.8

Notes: The universities are 110 top U.S. research universities, less eight schools with incomplete data. Means and growth rates of the expenditure proportion are weighted by expenditure.

Table 2
Research and Teaching Outputs and Productivity,
Public and Private Universities, 1981-1999

Faculty Indicator	University Classification		
	All	Public	Private
Mean Research Output			
Papers	1,183	1,173	1,204
Five-Year Citations	4,948	4,170	6,526
Mean Teaching Output			
Baccalaureate Degrees	3,010	3,795	1,417
Graduate Degrees	1,747	1,741	1,758
Weighted Mean Research Productivity			
Papers/Research Faculty	3.1	2.6	4.8
Five-Year Citations/Research Faculty	10.3	7.4	20.4
Weighted Mean Teaching Productivity			
Baccalaureate Degrees/Teaching Faculty	4.5	4.9	3.1
Graduate Degrees/Teaching Faculty	2.6	2.2	3.9

Notes: Means of research and teaching productivity are weighted by faculty size.

Table 3
Annual Percentage Growth Rates in Research and Teaching Productivity, Public and Private Universities, 1981-1999

Productivity Statistic	University Classification		
	All	Public	Private
Percentage Growth in Research Productivity			
Papers/Research Faculty	1.4	1.2	2.2
Five-Year Citations/Research Faculty	6.7	6.2	8.6
Percentage Growth in Teaching Productivity			
Baccalaureate Degrees/Teaching Faculty	0.8	1.2	-0.6
Graduate Degrees/Teaching Faculty	1.1	1.4	-0.1

Notes: The table covers 1981-1999 for papers and 1981-1995 for citations. Productivity growth rates are weighted by faculty size. All growth rates are in percents per year.

Table 4
Faculty Compensation by Rank, Public and Private Universities, 1981-1999

Faculty Indicator	University Classification		
	All	Public	Private
Means			
Assistant Professor	49.1	48.7	50.0
Associate Professor	59.3	58.5	61.2
Full Professor	81.9	79.4	87.4
All Ranks	64.7	62.6	69.5

Notes: Faculty compensation is expressed in thousands of 1992 dollars and includes fringe benefits in addition to wages.

Table 5
Aggregate Productivity Growth in University Research and Teaching,
(Shares in Total Productivity Growth in Parentheses)

University Classification	Papers/ Res. Faculty	Five-Year Citations/ Res. Faculty	Bacc. Degrees/ Teach. Faculty	Grad. Degrees/ Teach. Faculty
All Universities (N=102)				
Total Productivity Growth	0.701 (1.00)	8.625 (1.00)	0.585 (1.00)	0.470 (1.00)
Within University	0.846 (1.21)	9.998 (1.16)	0.801 (1.37)	0.512 (1.09)
Covariance	-0.374 (-0.53)	-1.518 (-0.18)	-0.251 (-0.43)	-0.221 (-0.47)
Between University	0.229 (0.33)	0.145 (0.02)	0.035 (0.06)	0.178 (0.38)
Public Universities (N=68)				
Total Productivity Growth	0.509 (1.00)	5.969 (1.00)	0.976 (1.00)	0.518 (1.00)
Within University	0.520 (1.02)	5.933 (0.99)	1.041 (1.07)	0.626 (1.21)
Covariance	-0.297 (-0.58)	-0.589 (-0.10)	-0.189 (-0.19)	-0.145 (-0.28)
Between University	0.287 (0.56)	0.625 (0.10)	0.123 (0.13)	0.037 (0.07)
Private Universities (N=34)				
Total Productivity Growth	1.534 (1.00)	20.019 (1.00)	-0.377 (1.00)	-0.064 (1.00)
Within University	1.880 (1.23)	22.878 (1.14)	-0.176 (0.46)	0.051 (-0.80)
Covariance	-0.514 (-0.34)	-2.582 (-0.13)	-0.190 (0.50)	-0.334 (5.22)
Between University	0.168 (0.11)	-0.278 (-0.01)	-0.010 (0.03)	0.219 (-3.42)

Notes: Productivity growth is the difference over 1981-1999. It is the arithmetic difference $X_T - X_1$ and not $(X_T - X_1)/X_1$. The decomposition follows equation (2). The sum of the components may differ slightly from the total because of rounding error.

Table 6
Aggregate Productivity Growth Within and Between
Groups of Public and Private Universities
(Shares in Total Productivity Growth in Parentheses)

Productivity Statistic	Papers/ Res. Faculty	Citations/ Res. Faculty	Bacc. Degrees/ Teach. Faculty	Grad. Degrees/ Teach. Faculty
All Universities (N=102)				
Total Productivity Growth	0.701 (1.00)	8.625 (1.00)	0.585 (1.00)	0.470 (1.00)
Within Group	0.755 (1.08)	9.339 (1.08)	0.709 (1.21)	0.403 (0.86)
Covariance	-0.022 (-0.03)	-0.424 (-0.05)	-0.069 (-0.12)	-0.030 (-0.06)
Between Group	-0.032 (-0.05)	-0.291 (-0.03)	-0.055 (-0.09)	0.097 (0.21)

Notes: Productivity growth is the difference over 1981-1999. It is the arithmetic difference $X_T - X_1$ and not $(X_T - X_1)/X_1$. The decomposition follows equation (3). The sum of the components may differ slightly from the total because of rounding error.

Table 7
Public Universities: NLLS Research Productivity Equations,
Papers and Citations Per Research Faculty
(t-Statistics in Parentheses)

Variable or Statistic	Papers per Research Faculty			Citations per Research Faculty		
	7.1	7.2	7.3	7.4	7.5	7.6
Time Period	1982-1999	1982-1999	1982-1999	1982-1995	1982-1995	1982-1995
University Fixed Effects	No	No	Yes	No	No	Yes
Time Trend	-0.026***	-0.015***	0.009***	-0.016***	0.002	0.056***
	(-10.9)	(-7.6)	(8.6)	(-3.6)	(0.4)	(24.5)
Nonfederal Stock of R&D per Research Faculty$_{-1}$ (δ_R)	0.477***	0.478***	0.566***	-0.043	-0.113*	0.738*
	(6.3)	(5.0)	(4.1)	(-0.9)	(-2.0)	(2.0)
Log (Stock of R&D per Research Faculty$_{-1}$) (β_R)	0.707***	0.455***	0.297***	0.831***	0.544***	0.272***
	(31.4)	(21.7)	(16.3)	(20.6)	(13.8)	(6.7)
Log (Endowment per Research Faculty$_{-1}$)		0.021***	-0.019***		0.050***	-0.005
		(3.3)	(-4.4)		(4.5)	(-0.6)
Log (Graduate Students per Research Faculty$_{-1}$)		0.431***	0.277***		0.312***	-0.178***
		(15.7)	(12.8)		(6.3)	(-3.5)
Log (Post-Doctoral Students per Research Faculty$_{-1}$)		0.138***	0.004		0.218***	0.042***
		(14.2)	(0.8)		(12.4)	(3.3)
Log (Research Faculty$_{-1}$)	-0.245***	-0.224***	-0.400***	-0.301***	-0.325***	-0.807***
	(-13.3)	(-15.1)	(-32.4)	(-9.0)	(-11.2)	(-30.1)
Number of Universities	68	68	68	68	68	68
Number of Observations	1054	1054	1054	831	831	831
Root Mean Squared Error	0.406	0.325	0.073	0.573	0.534	0.122
Adjusted R^2	0.625	0.760	0.988	0.573	0.679	0.983

Notes: Dependent variables are logarithms of papers and citations per research faculty-equivalent. So as to avoid division error bias, research faculty-equivalents used in the right-hand side variables are lagged one year relative to research faculty equivalents on the left. *** Significant at the one-tenth of one per cent level. **Significant at the one per cent level. * Significant at the five per cent level.

Table 8
Private Universities: NLLS Research Productivity Equations, Papers and Citations Per Research Faculty (t-Statistics in Parentheses)

Variable or Statistic	Papers per Research Faculty			Citations per Research Faculty		
	8.1	8.2	8.3	8.4	8.5	8.6
Time Period	1982-1999	1982-1999	1982-1999	1982-1995	1982-1995	1982-1995
University Fixed Effects	No	No	Yes	No	No	Yes
Time Trend	-0.024***	-0.017***	0.003	-0.015***	0.008*	0.042***
	(-8.3)	(-5.4)	(1.8)	(-3.9)	(2.1)	(14.1)
Nonfederal Stock of R&D per Research Faculty$_{-1}$ (δ_R)	0.617***	1.352***	0.315	-0.467***	-0.627***	0.891
	(3.8)	(3.9)	(1.6)	(-8.4)	(-56.8)	(1.7)
Log (Stock of R&D per Research Faculty$_{-1}$) (β_R)	0.699***	0.443***	0.304***	0.793***	0.325***	0.295***
	(21.0)	(13.4)	(11.4)	(16.9)	(10.6)	(6.8)
Log (Endowment per Research Faculty$_{-1}$) [a]		0.094***	0.144***		0.121***	0.104**
		(5.4)	(6.9)		(5.1)	(3.1)
Log (Graduate Students per Research Faculty$_{-1}$)		0.077**	0.068*		-0.036	-0.072
		(2.7)	(2.1)		(-1.0)	(-1.4)
Log (Post-Doctoral Students per Research Faculty$_{-1}$)		0.263***	0.031		0.539***	0.033
		(11.7)	(1.5)		(17.2)	(1.0)
Log (Research Faculty$_{-1}$)	-0.264***	-0.214***	-0.381***	-0.193***	-0.100***	-0.553***
	(-10.9)	(-10.6)	(-15.7)	(-5.1)	(-3.5)	(-14.1)
Number of Universities	34	34	34	34	34	34
Number of Observations [a]	475	475	475	475	475	475
Root Mean Squared Error	0.318	0.260	0.072	0.499	0.364	0.117
Adjusted R^2	0.558	0.705	0.977	0.584	0.779	0.977

Notes: Dependent variables are logarithms of papers and citations per research faculty-equivalent. So as to avoid division error bias, research faculty-equivalents used in the right-hand side variables are lagged one year relative to research faculty equivalents on the left. [a] By coincidence data on endowments of private universities end in 1995 so that numbers of observations on papers and five-year citations are the same. *** Significant at the one-tenth of one per cent level. **Significant at the one per cent level. * Significant at the five per cent level.

Table 9
Public Universities: OLS and NLLS Teaching Productivity Equations, Baccalaureate and Graduate Degrees Per Teaching Faculty
(t-Statistics in Parentheses)

Variable or Statistic	Bacc. Degrees per Teaching Faculty			Grad. Degrees per Teaching Faculty		
	9.1	9.2	9.3	9.4	9.5	9.6
Estimation Method	OLS	OLS	OLS	OLS	NLLS	NLLS
Time Period	1982-1999	1982-1999	1982-1999	1982-1999	1982-1999	1982-1999
University Fixed Effects	No	No	Yes	No	No	Yes
Time Trend	0.003 (1.5)	-0.001 (-0.6)	0.007*** (6.7)	0.011*** (4.0)	-0.008*** (-3.8)	-0.001 (-0.8)
Log (Undergrad. Enrollment per Teaching Faculty$_{-1}$)	0.790*** (31.9)	0.604*** (23.9)	0.487*** (12.2)			
Log (Endowment per Teaching Faculty$_{-1}$)		-0.007 (-1.5)	-0.003 (-0.5)		0.031*** (4.8)	-0.020** (-3.2)
Log (Graduate Students per Teaching Faculty$_{-1}$)		0.354*** (16.1)	0.065* (2.2)	0.409*** (16.7)	0.248*** (8.7)	0.408*** (10.6)
Log (State Appropriations per Teaching Faculty$_{-1}$)		-0.243 (-11.8)	-0.017 (-0.9)		0.068** (2.6)	0.061** (3.2)
Nonfederal Stock of R&D per Teaching Faculty$_{-1}$ (δ_I)					-0.308*** (-4.5)	-0.090 (-1.2)
Log (Stock of R&D per Teaching Faculty$_{-1}$) (β_I)					0.130*** (5.0)	0.268*** (9.3)
Log (Teaching Faculty$_{-1}$)	0.106*** (8.1)	0.069*** (4.9)	-0.354*** (-7.8)	-0.066*** (-3.8)	0.007 (0.4)	-0.135*** (-7.5)
Number of Universities	68	68	68	68	68	68
Number of Observations	886	886	886	886	886	886
Root Mean Squared Error	0.276	0.240	0.069	0.346	0.320	0.088
F	353.5+++	280.7+++	409.2+++	144.3+++	--	--
Adjusted R^2	0.544	0.655	0.971	0.327	0.426	0.957

Notes: Dependent variables are logarithms of undergraduate and graduate degrees per teaching faculty-equivalent. To avoid division error bias teaching faculty used in the right-hand side variables are lagged one year relative to teaching faculty on the left. *** Significant at the one-tenth of one per cent level. **Significant at the one per cent level. * Significant at the five per cent level. +++ F-statistic is significant at the one-tenth of one percent level.

Table 10
Private Universities: OLS and NLLS Teaching Productivity Equations, Baccalaureate and Graduate Degrees Per Teaching Faculty
(t-Statistics in Parentheses)

Variable or Statistic	Bacc. Degrees per Teaching Faculty			Grad. Degrees per Teaching Faculty		
	10.1	10.2	10.3	10.4	10.5	10.6
Estimation Method	OLS	OLS	OLS	OLS	NLLS	NLLS
Time Period	1982-1999	1982-1999	1982-1999	1982-1999	1982-1999	1982-1999
University Fixed Effects	No	No	Yes	No	No	Yes
Time Trend	0.002	0.007*	-0.000	0.003	-0.013**	0.006***
	(0.8)	(2.4)	(-0.1)	(0.5)	(-3.2)	(3.5)
Log (Undergrad. Enrollment per Teaching Faculty$_{-1}$)	0.631***	0.731***	0.658***			
	(16.4)	(18.2)	(7.1)			
Log (Endowment per Teaching Faculty$_{-1}$)		-0.062***	0.073**		-0.118***	-0.025
		(-4.2)	(3.3)		(-3.9)	(-1.1)
Log (Graduate Students per Teaching Faculty$_{-1}$)		-0.072**	-0.021	0.388***	0.146**	0.308***
		(-3.7)	(-0.7)	(11.7)	(3.0)	(8.6)
Log (State Appropriations per Teaching Faculty$_{-1}$)		-0.022***	-0.003		0.014**	0.002
		(-8.9)	(-1.4)		(3.0)	(0.9)
Nonfederal Stock of R&D per Teaching Faculty$_{-1}$ (δ_I)					0.492	-0.130
					(0.9)	(-0.5)
Log (Stock of R&D per Teaching Faculty$_{-1}$) (β_I)					0.285***	0.154***
					(6.2)	(6.2)
Log (Teaching Faculty$_{-1}$)	-0.175**	-0.207***	-0.359***	0.228***	0.217***	-0.282***
	(-8.1)	(-10.2)	(-4.0)	(5.9)	(6.4)	(-12.6)
Number of Universities	34	34	34	34	34	34
Number of Observations	475	475	475	475	475	475
Root Mean Squared Error	0.262	0.236	0.067	0.462	0.428	0.079
F	105.3+++	84.2+++	294.6+++	50.6+++	--	--
Adjusted R^2	0.398	0.513	0.960	0.239	0.347	0.978

Notes: Dependent variables are logarithms of undergraduate and graduate degrees per teaching faculty-equivalent. To avoid division error bias teaching faculty used in the right-hand side variables are lagged one year relative to teaching faculty on the left. *** Significant at the one-tenth of one per cent level. **Significant at the one per cent level. * Significant at the five per cent level. +++ F-statistic is significant at the one-tenth of one percent level.