Minerva
DOI 10.1007/s11024-017-9330-4

The Scientific Research Output of U.S. Research Universities, 1980–2010: Continuing Dispersion, Increasing Concentration, or Stable Inequality?

Steven Brint[1] · Cynthia E. Carr[1]

Abstract Extending and expanding Geiger and Feller's (1995) analysis of increasing dispersion in R&D expenditures during the 1980s, the paper analyzes publication and citation counts as well as R&D expenditures for 194 top producers using Web of Science data. We find high and stable levels of inequality in the 1990s and 2000s, combined with robust growth both in the system and on individual campuses, considerable opportunities for short-range mobility and very limited opportunities for long-range mobility. Initial investments in research, private control, and the capacity of wealthy institutions to attract productive faculty are associated with high levels of scientific output. New entrants to the system and those that leave the system are both clustered near the bottom of the hierarchy.

Keywords Higher education · Research productivity · Institutional stratification · Institutional mobility

Introduction

This paper analyzes growth, inequality, and mobility in the population of top U.S. research universities during the period 1980–2010. The paper focuses on the question of whether scientific output continued to disperse across U.S. research universities in the years after 1990, as researchers found it had in the 1980s, or whether, alternatively, output became more concentrated in the hands of a smaller number of leading universities. A third possibility, also considered here, is that relations established in the system in the 1980s remained generally stable through the end of the period. The analysis is important because of its implications for

A1 ✉ Steven Brint
A2 brint@ucr.edu

A3 [1] University of California, Riverside, CA, USA

Journal : Small-ext 11024 | Dispatch : 12-7-2017 | Pages : 22
Article No. : 9330 | □ LE | □ TYPESET
MS Code : MINV-D-16-00068 | ☑ CP | ☑ DISK

science policy. Some policymakers and university leaders have expressed concern that continued dispersion dilutes the quality of research produced by the leading institutions. Others have expressed concern that increasing concentration is restricting the capacity of the system as a whole to generate important new ideas and findings.

We will argue that neither of these two concerns captures the key features of the development of the U.S. system of academic science. To evaluate the significance of patterns of dispersion or concentration, it is necessary to examine changes in inequality in relation to other features of the system, namely, growth and mobility. Whether either increasing concentration or stable inequality should be considered problems depends, in large measure, on whether the system is growing and how much mobility exists in the system. Concentration may be tolerable or even beneficial if the system as a whole, as well as the great majority of individual campuses, are increasing in output. Similarly, high levels of concentration may be acceptable to the extent that opportunities for mobility also exist in the system.

Growth, Inequality, and Mobility

Thus, to understand how scientific research output in U.S. research universities has developed in recent decades, it is necessary to distinguish (1) *system (and individual campus) output*, (2) *trends in dispersion* and *concentration*, and (3) *mobility opportunities.*

(1) *System output* can be defined as the total output of all institutions using measures such as R&D expenditures, publications, and citations (and potentially other outputs such as patents and licenses). Individual campus outputs can be defined in the same way. Individual institutions in the system may or may not contribute steadily to system growth. Moreover, growth may be consistent with either increasingly equal, increasingly unequal, or stable distributions of expenditures and outputs among institutions in the system, and it may be consistent with high or low levels of mobility. (2) *Dispersion/concentration* can be defined as the change in levels of inequality over time using measures such as the Gini coefficient and interquartile shifts in shares of production. (3) *Mobility* can be defined as the extent of opportunities for changing rank within the system using measures such as the proportion of institutions experiencing inter-decile movement over time. In highly stratified systems the great majority of institutions maintain their relative positions, with minor fluctuations in rank, and few institutions experience long-range upward or downward mobility. In less stratified systems, the opposite is true.

Our analysis shows a system marked by greatly increased system- and campus-level output *and* stably high levels of inequality, with considerable short-range but very limited long-range mobility opportunities for individual institutions. The stable and high levels of inequality we find clearly have not restricted either system or individual campus level output. It seems more likely that they have been a spur to it, given the competition institutions experience to move up the ranks and the opportunities that have existed for short-range mobility.

Journal : Small-ext 11024 Dispatch : 12-7-2017 Pages : 22
Article No. : 9330 □ LE □ TYPESET
MS Code : MINV-D-16-00068 ☑ CP ☑ DISK

Extending Geiger and Feller's Analysis

The paper is designed as an extension and expansion of an article published in 1995 by the higher education scholars Roger L. Geiger and Irwin Feller (hereafter G&F). G&F documented the dispersion of research and development expenditures beginning in the 1960s, as part of a national policy to create larger numbers of research universities. During the decade of the 1980s, they found a declining share of total R&D spending by top quartile universities, with most of the gain going to second quartile institutions. Bottom quartile institutions also gained share. G&F attributed their findings to the likelihood that "distinguished universities operate near a production frontier defined by a maximally feasible percentage of faculty already conducting funded research and by physical constraints on the expansion of research facilities" (p. 347). By contrast, they argued, second-tier universities shared many of the characteristics of the leading universities, such as moderate teaching loads, up-to-date laboratories, and first-rate research in some fields and were thus in a position to capitalize on the expansion of resources available to support research.

G&F's work provided an alternative perspective to a series of reports of the period expressing the fear that too many universities competing for research funds would threaten "a slow erosion of the average quality of the nation's scientific effort" (Rosenzweig 1992: 18) (see also House of Representatives 1992; OTA 1991). G&F argued instead that continued dispersion principally benefited institutions of above average quality, and generally caused continued improvement in them, thereby adding to the nation's scientific prowess.

G&F focused solely on R&D expenditures. We examine two additional indicators of scientific productivity that were not available at the time G&F published their work: publications and citations.[1] Although the capacity to generate R&D expenditures is correlated with outcomes, it is the outcomes themselves that provide measures of research impact (see, e.g., Charlton and Andras 2007). Research volume, or publication count, is an indicator of the steadiness of an institution's research output and is one measure of its capacity for influence. Citations are used as major criteria in international measures of an institution's scientific eminence, such as the Shanghai Jiao Tong University (SJTU) rankings of world universities (Charlton and Andras 2007; see also Pouris 2007). Although it is true that some lightly cited articles have an outsized influence on major developments in science, as Adams and Griliches (1998) observe, "They [citations] are the best measure that we have" for analyzing scientific impact (p. 2).

G&F identified institutional characteristics they considered likely to be associated with scientific productivity, but did not investigate the influence of these characteristics empirically. We conduct such an empirical examination. We examine the institutional factors associated with higher levels of output in each of the three measures of productivity we investigate. We focus on initial and continuing investments in research, financial and human resources capacity to

[1] While they represent an outcome of increasing interest to students of scientific research (see, e.g., Owen-Smith 2003), patents and licenses are produced at a fractional rate as compared to publications and citations. We do not include them in this paper.

Journal : Small-ext 11024 | Dispatch : 12-7-2017 | Pages : 22
Article No. : 9330 | □ LE | □ TYPESET
MS Code : MINV-D-16-00068 | ☑ CP | ☑ DISK

conduct research, and other institutional advantages (notably, private control and operation of a medical school) that may affect the success of the research enterprise.

We focus on the same set of institutions identified by G&F as the top research institutions at the beginning of their study period. This strategy allows us to examine changes within a fixed population, the standard approach to longitudinal analysis. At the same time, we recognize that the system of research universities can also change through the entrance of new universities and the exit of those that no longer produce enough science for research to be considered a central mission. We characterize new entrants and, using 2010 data, show that both those institutions that have more recently entered the system and those from the G&F sample that have exited it tend to cluster near the bottom of the research university hierarchy, resulting in little change in the overall shape or levels of inequality, but adding to the mobility opportunities in the system.

Previous Literature

Academic science is highly stratified both internationally and within the United States. The top eight countries produced nearly 85% of the top 1% cited papers between 1993 and 2001, and the next nine produced 13% of these papers, indicating a "stark disparity" between the first and second strata of countries in scientific impact, as well as between these countries and the remaining countries in the world (King 2004). Within the United States, a similar pattern exists: Our calculations indicate that the 108 Carnegie "very high research" universities—fewer than 5% of the more than 2,500 4-year colleges and universities in the United States—produced some three-quarters of the papers catalogued in the Web of Science (WoS) in 2010 from high-quality peer-reviewed journals. The 99 Carnegie "high research" universities at the next level produced another 15% of WoS papers in 2010 (authors' calculations).

In the mid-1990s, theorists debated whether the scientific community could expect a still more stratified system of research production in the future or one in which scientific output expanded and dispersed across institutions. Among those who expected increasing stratification, Ziman (1994) argued that powerful forces of concentration based on excellence are "endogenous to science" and would lead to greater concentration over time. Merton's (1968) theory of "accumulative advantage" provided one justification for expecting higher levels of concentration among elite research universities. The much higher salaries of professors at these universities and their capacity to attract talented graduate students and postdoctoral scholars were among the forces Ziman identified as supporting greater concentration. Economists added complementary emphases based on the average and marginal costs of scientific production. Adams and Griliches (1998) argued, for example, that the leading universities, because of stronger human and technical infrastructure, have lower costs of performing research than less prestigious universities and therefore have a comparative advantage in generating high quality, important, and highly cited research.

By contrast, other theorists focused on the influence of entrepreneurialism and mimetic pressures as bases to justify their expectations for continued dispersion in

Journal : Small-ext 11024 | Dispatch : 12-7-2017 | Pages : 22
Article No. : 9330 | □ LE | □ TYPESET
MS Code : MINV-D-16-00068 | ☑ CP | ☑ DISK

an expanding scientific field. Gibbons et al. (1994) anticipated that the post-World War II expansion of research and educational systems, coupled with the "inexorable logic of entrepreneurial fund-raising," would encourage a dispersion of scientific research output as well as its reconfiguration into larger and more productive interdisciplinary groups. Halffman and Leydesdorff (2010) argued that senior administrators' tendency to imitate the leaders in their field—what others have called the pressures of institutional isomorphism—would produce a "global conformation of performance standards" among institutions competing with one another for eminence, and consequently greater equality in output among these competing institutions. Governments sought to augment these mimetic pressures, beginning in the 1980s, through the introduction of performance-based funding and ranking systems (Hicks 2012).

A third position is also evident in the debate. Hicks and Katz (2011) argued that political and social pressures for the more equitable distribution of funding opportunities could lead to greater dispersion of access to resources for research, while the unequal distribution of talent and infrastructure would nevertheless result in a continued, and perhaps increasing, concentration of highly-cited articles produced by top-tier universities.

The empirical evidence bearing on these rival predictions has been mixed. Some field-level studies support proponents of the increasing concentration thesis. McNamee and Willis (1994) found variation in levels of concentration across four fields studied between 1960 and 1995, but, after periods of dispersion, institutional representation in leading journals generally reverted to "an inner circle of prestigious academic institutions." Adams and Griliches (1998) examined eight fields and found a correlation between citations and lagged R&D expenditures. They concluded that the larger research programs in the leading universities produced research that was more frequently cited and, by implication, of higher quality. In addition, private universities generated more research output per additional dollar of R&D than public universities. Adams et al. (2005) pointed to another infrastructure advantage in the growing size of scientific teams. Studying publications over the period 1981–1999, they found that team sizes had increased by 50% over the period. The increase in team size was most evident at the most prestigious universities, allowing for increases in "scientific output and influence" at these institutions. Others found that the surge in patenting and licensing that occurred following the passage of the Bayh–Dole Act of 1980 had a net positive effect on publications and citations, creating a new advantage for entrepreneurial universities, most of which were clustered among top research producers (Owen-Smith 2003).

Other studies supported the dispersion thesis. At the international level, it is clear that dispersion has been the dominant trend. Studies of scientific output from the 1990s through the mid-2000s document the declining share of worldwide scientific output held by the United States and the growing representation of European countries, such as England and Germany, and East Asian countries, such as China and Japan, in the world share of papers and citations (Javitz 2006; King 2004). Halffman and Leydesdorff (2010) showed similar findings for the top decile of world universities, which slowly but steadily lost ground in the 1990s and 2000s. Moreover, the Gini coefficient for the 100 most prominent world universities

Journal : Small-ext 11024 | Dispatch : 12-7-2017 | Pages : 22
Article No. : 9330 | □ LE | □ TYPESET
MS Code : MINV-D-16-00068 | ☑ CP | ☑ DISK

dropped during the period 1990–2007 (ibid.). As world universities shifted toward production valued in world rankings, oligopolistic tendencies declined rather than increased. Evidence from individual countries is less clear. In countries like Australia in which universities continue to be relatively undifferentiated by quality, scientific productivity became more dispersed over time (Ville et al. 2006). But evidence from other countries that have attempted to stimulate competition through performance-based funding and ranking has as yet not been reported in the literature at the institutional level.

Overview of the Analyses

We pursue the analysis in four steps. (1) We begin by discussing the growth of scientific research output—as measured by R&D expenditures, publication counts, and citations. The degree of expansion of the system as a whole is an essential contextual feature of the current structure of scientific research in the United States. (2) Using the Gini coefficient as our measure of inequality, we then examine the extent to which research output became more or less concentrated between 1980 and 2010. The Gini coefficient provides a standard measure of concentration and dispersion in a population. Following G&F, we also discuss changes in share by quartiles as a second perspective on inequality. (3) We then turn our attention to mobility, examining inter-decile mobility patterns. This analysis allows us to identify in a highly textured way how much long- and short-term mobility has existed in the system over the 30-year period. (4) Finally, we conduct regression analyses on publications and citations to identify the covariates associated with scientific research productivity during the period.

Data and Methods

Sample

G&F examined the top 194 research universities in terms of R&D spending using 1980s data from the NSF *Survey of Research and Development Expenditures at Universities and Colleges/Higher Education Research and Development Survey*, made available by the National Center for Science and Engineering Statistics (NCSES). To conduct a longitudinal analysis, we retained their sample. We were forced to drop six of the institutions, either because they merged with other institutions or, in one case, because we could not identify the institution in IPEDS, leaving a sample of 188.[2] Another 12 institutions were missing from the data set we

[2] The mergers included the Oregon Graduate Institute of Science and Technology into Oregon Health and Science University (OHSU) in 2001; the Medical College of Pennsylvania into MCP Hahnemann Medical College in 1993; MCP Hahnemann University with Drexel University College of Medicine in 2002; Hahnemann Medical School with Drexel University College of Medicine in 2003. The University of Maryland Baltimore Professional Schools publish as part of the University of Maryland, Baltimore. Finally, we were unable to ascertain the identity of the institution called Polytechnic University in G&F's study.

Journal : Small-ext 11024 | Dispatch : 12-7-2017 | Pages : 22
Article No. : 9330 | □ LE | □ TYPESET
MS Code : MINV-D-16-00068 | ☑ CP | ☑ DISK

used to code institutional characteristics, and were thus not included in our regression analyses.[3] These 12 institutions are included in all other analyses.

Dependent Variables

As in G&F, our measurement of total R&D expenditures included all sources of research funding: federal, state and local, industry, foundations and other non-profits, and institutional self-funding. Total R&D expenditures are expressed in 2010 dollars.

The most widely used source for publications and citations data is the Web of Science (WoS) compiled by Thomson Reuters (see, e.g., Javitz 2006; National Science Board 2014; Toutkoushian et al. 2003). Thomson Reuters indexes journals to the WoS based on specific criteria in an effort to include only high-quality, high-impact academic work. WoS currently features more than 12,000 high-impact journals across disciplines, as well as citation count information.[4] WoS counts relatively few books and conference proceedings, a limitation of this source. However, papers are the primary vehicle of publication in the sciences and the focus of WoS on the more prestigious journals also seems appropriate for purposes of measuring scientific output that meets minimum quality standards.[5]

We measured research volume simply as the count of publications per institution in WoS for each target year, beginning in 1980 and proceeding at 5-year intervals. We counted the institutional affiliations of all co-authors of publications that included more than one author equally. This counting convention is labeled as "whole count" data and compares to "fractional counts," in which each co-author is credited with a proportional fraction of credit (e.g., in the case of four co-authors, one-quarter credit). In an era in which the number of co-authors is increasing in many fields, whole count data provides much larger publication (and citation) counts for institutions than fractional count data. We used whole counts because one of the reasons for the impressive growth in U.S. scientific output is the greater capacity of university researchers to leverage the talents of co-authors. We concluded that this is a real contribution of new modes of scientific production and should be fully credited as such.[6]

[3] These 12 institutions included the University of Illinois at Urbana-Champaign, the University of Massachusetts at Amherst, Missouri University of Science and Technology, New Mexico State University, the University of Texas Health Science Center at San Antonio, the University of Texas Medical Branch at Galveston, the University of Texas at Dallas, and the University of Texas M.D. Anderson Cancer Center, the University of Maryland Center for Environmental Science, the University of Texas Health Science Center at Houston, the University of Puerto Rico Mayaguez, and the Uniformed Services University of the Health Sciences.

[4] Although the number of journals catalogued in WoS has grown over time, it is possible that researchers at lower-ranked institutions may find their research niches in more applied fields that are not included in WoS data.

[5] WoS is somewhat less useful for those social science disciplines, such as sociology and political science, in which book publication is important. It is least useful for the humanities in which book publishing is central to the establishment of authors' and institutions' reputations.

[6] Researchers who use fractional counting find that the number of papers per researcher is rising at a much lower rate. See, e.g., Fanelli (2010).

Journal : **Small-ext 11024**	Dispatch : **12-7-2017**	Pages : **22**
Article No. : **9330**	□ LE	□ TYPESET
MS Code : **MINV-D-16-00068**	☑ CP	☑ DISK

We measured citation count as the number of times a publication catalogued in the WoS cited an article produced by a target institution during a target year, beginning in 1980 and proceeding at 5-year intervals. We began by taking all publications from 1980 and tracing citation counts on these publications through 2016, or 36 years in all. We then took the publications for each institution for 1985 and traced their citation counts through 2016, or 31 years in all. We continued this procedure through 2010.

Growth in citation counts is a function of the number of publications catalogued, the growth of scientific infrastructure, and the growth of scientific networks over time, and we can therefore expect that papers published more recently will, in general, tend to accumulate more citations than those published earlier in the period. However, there is an exception to this rule: Publications originating prior to 2010 have had a longer period of time to accumulate citations than those originating in 2010. Publications from 2010 have had only 6 years to accumulate citations, and publications typically take at least two to 3 years to begin to accumulate citations at a high rate. We have therefore dropped 2010 from the citations regression analysis as it offers immature data, and would give readers the false sense that citations are decreasing when every other indicator suggests the opposite (see Fig. 3). Data from 2010 are included in all other analyses.

Growth and Inequality Measures

We used percentage changes across decades and across the entire 30-year period to describe the expansion of scientific research in terms of institutional share on all three measures of scientific contribution (R&D expenditures, publications, and citations). We examine institutions as a whole rather than output per capita.[7]

We used the Gini coefficient to describe changes in levels of inequality in the system. Gini is a widely-used indicator of inequality in resource distribution and one that is applicable to inputs and outputs of scientific research productivity where institutions are the unit of analysis (see, e.g., Halffman and Leydesdorff 2010). The Gini coefficient is a measure of inequality based on the proportions of units along the Lorenz curve, where 0 represents complete equality in distribution of the resource, with equal shares controlled by every unit, and 1 represents complete inequality in distribution, with the resource controlled by one unit only. The lower the Gini, the more equality; the higher the Gini the less equality. Comparisons of Gini by decade provide a sense of the extent to which research dispersed across institutions or became more concentrated.

[7] We consider the output of the institution as a whole to be a better measure than per capita output because one advantage of larger institutions is precisely that they produce in a wide variety of areas. This increases their visibility and prominence. Per capita growth and mobility tables provide a slightly different picture of the trajectory of the system as a whole and of individual institutions. Medical and engineering institutions fare somewhat better in per capita analyses, for example. A few small campuses, such as Rockefeller University, are highly productive on a per capita basis but the small size of their faculty has led to declining rank in output measures over time. The results of per capita analyses do in other respects tend to closely mirror those of the whole institution analyses that we use in the paper. Per capita results are available on request.

Journal : Small-ext 11024 | Dispatch : 12-7-2017 | Pages : 22
Article No. : 9330 | ☐ LE | ☐ TYPESET
MS Code : MINV-D-16-00068 | ☑ CP | ☑ DISK

For a second perspective on inequality, we also categorized institutions by the R&D quartile in which they were located at the beginning of the period and examined changes in quartile share over time. This analysis allowed us to investigate the extent to which the second quartile captured a larger share of research input and output over time, and therefore to follow up on a notable finding by G&F for R&D expenditures during the 1980s.

Inter-Decile Mobility Measures

Examination of inter-decile mobility allows for a highly textured treatment of stratification within the system. We composed deciles of 19 institutions each, except for the bottom decile which was composed of 17 institutions. We examined changes in decile composition over three decades: 1980–1990, 1990–2000, and 2000–2010. We measured inter-decile mobility as movement from a location anywhere in one decile to a location anywhere in another decile.[8] For each dependent variable, we counted the number of institutions that remained in each decile from decade to decade, and the number of gainers and losers in each decile, as measured by inter-decile mobility. We measure short-range mobility as the number and proportion of institutions that moved into the next higher or lower decile during the period. We measure long-run mobility as the number and proportion of institutions that moved up or down *more than one decile* over the 30-year period.

Independent Variables in the Regression Analysis

To investigate the sources of high campus levels of scientific output, we sought to identify institutional characteristics related to initial and continuing investments in research, financial and human capacity to engage in research, and other institutional factors plausibly linked to research productivity.

R&D quartile at the beginning of the period is a dummy-coded variable reflecting quartiles based on the G&F selection and ranking with respect to total R&D spending. This variable is a measure of initial investments in research. It allows us to investigate the effects of original ranking, as well as the extent to which top quartile institutions have gained more over time relative to lower-ranked institutions. We also coded *institutional R&D* from NCSES (NSF 2015). It is a primary indicator of continuing institutional commitments to fostering a robust research environment. A wide variety of allocations are included in this variable, including internal grants, scientific infrastructure spending, and internally-funded course remissions.[9]

[8] Inter-decile mobility can be measured in more than one way. An alternative measure, for example, would be to count any movement of 19 or more places as inter-decile mobility. Such a measure fails, however, to capture the concept of inter-decile movement accurately in our view, because the concept signifies location in one decile at time 1 and location in another decile during a later period. The exact location within the decile is immaterial.

[9] Although we expected high levels of collinearity between institutional R&D and R&D quartile at the beginning of the period, in fact the correlation between the two variables (r = 0.30) was not too high to preclude the use of both. No variable in this study has a VIF of over 2.5.

The capacity measures focus on financial strength and available human resources. G&F recommended use of instructional expenditures as a measure of institutional financial strength. However, this variable proved to be collinear with several others in our model. We consequently substituted *student subsidy*, as suggested by Winston (1999, 2004). Student subsidy is a measure of the education and related expenses not covered by tuition. It is a measure of the discretionary funds that the institution chooses to dedicate to education and related expenses from state subsidies and endowments. As an independent variable it does not pose the same problems of collinearity as instructional expenditures. We obtained data on student subsidy from the Delta Cost Study data set (AIR 2014).[10] We also obtained data on number of *full-time faculty* from the Delta Cost Study data set (AIR 2014). This variable includes full-time, non-tenure track faculty, as well as those who are tenured or on the tenure track. Counts of tenured and tenure-track faculty were not collected consistently across institutions during the period of this study, and use of full-time faculty is a common proxy (Dundar and Lewis 1998). In addition, we created an interaction between *student subsidy* and *full-time faculty* in order to explore potential differences in faculty productivity based on the wealth of institutions.

Two other institutional characteristics are often associated in the literature with higher levels of scientific research output: private control and operation of a medical school. Private research universities in the United States dominate status rankings (USNWR 2015) and pay significantly higher salaries than public universities (AAUP 2015). They are consequently in a position to attract and retain the most productive faculty members. All else equal, it would seem likely that they would obtain more resources for producing research and to produce more research output as well. We coded *control* as public or private, non-profit governance using the Delta Cost Study database. Medical research holds a distinctive position in American research universities. In part because of generous funding from the National Institutes of Health and foundations such as the Howard Hughes Medical Institutes and the Robert Wood Johnson Foundation, differences in publication rates for fields in or closely related to biomedicine are significantly higher than rates in other fields (Times Higher Education 2011). By a large measure, medical schools are also the most popular recipient of funding from individual and family foundations. We included two factor variables, *has a medical school*, coded 0 for no medical school at the institution, 1 for the presence of a medical school, and *is a medical school*, coded 1 for institutions that are themselves free-standing medical schools or health science institutions and 0 for all other institutions.

We also included two control variables. We included *panel year* to control for expansionary trends over the period. We coded academic year in 5-year panels. Finally, it is necessary to control for the few multi-campus universities that report system-wide data, which may lead to over-counts of the contributions of the main campus (see Jaquette and Parra 2016). We included a dummy variable (labeled *system reporting*) for campuses that report data to IPEDS in this fashion.

[10] Because student subsidy is mathematically derived, there were 16 cases of negative subsidy which we converted to 0 as no subsidy was offered at those institutions in those years.

Journal : Small-ext 11024 | Dispatch : 12-7-2017 | Pages : 22
Article No. : 9330 | □ LE | □ TYPESET
MS Code : MINV-D-16-00068 | ☑ CP | ☑ DISK

The Appendix provides descriptive statistics on the independent and dependent variables used in these analyses. As shown in the Appendix, several of the independent variables are strongly left skewed. We therefore logged all continuous variables to normalize their distributions. In addition, there were three missing values for student subsidy, one missing value for full-time faculty, and one missing value for institutional R&D. In each case, we interpolated values from data in previous and succeeding years.

Regression Modeling Strategy

We gathered data over 20 years (1990–2010) in 5-year increments for 188 institutions of G&F's original sample of top performing institutions in terms of R&D spending. The regression therefore reflects trends for the G&F population of institutions only and is consequently not generalizable to the population of higher education institutions across the U.S. Observations drawn for the same group of cases over time produces panel data, where universities are observed multiple times. Panel data such as these make ordinary least squares regression inappropriate because observations of the same university over time are not independent. One standard analytical process is to employ a fixed effects model (FEM), which removes unobserved time invariant characteristics of universities by analyzing only the variation within universities over time (Halaby 2004). A key drawback to the FEM is that it cannot produce parameter estimates of time-invariant characteristics such as some that are central to our study–initial R&D spending level, control, and presence of a medical school—because they would be eliminated with all of the between case-variation.

The alternative random effects model (REM) addresses the problem of unmeasured, time-invariant university-specific heterogeneity with a university-specific error term in addition to the classic error term. If these "random intercepts" are uncorrelated with the covariates on the right hand side of the regression equation, the REM has all the unbiased properties of the FEM as well as greater efficiency. However, Hausman tests suggest that we cannot assume zero correlation between the random intercepts and our covariates of interest. Thus, to proceed, we implement a hybrid approach (Allison 2009). The hybrid model simultaneously estimates parameters on two versions of the time-variant covariates. One version is the time-invariant university means. The other is a version in which the university-specific means are subtracted from each of the time-varying covariates. Conceptually, this divides the variation in each time-varying covariate into a "within" and a "between" component. The time–invariant covariates enter the model in their natural form, and we use the REM to estimate the effects of each (see Allison 2009 for a full discussion). The coefficients on the "within" versions of the time-invariant covariates will be identical to those produced with the FEM, but the hybrid model also allows us to produce estimates of the effects of time-invariant covariates and the "between" university variation in time-varying covariates. Panel data such as these often yield heteroskedastic and serially correlated error terms and we therefore implement a variance/covariance matrix that is robust to both (Rogers 1993).

We set out our hybrid model as follows:

Journal : Small-ext 11024 | Dispatch : 12-7-2017 | Pages : 22
Article No. : 9330 | □ LE | □ TYPESET
MS Code : MINV-D-16-00068 | ☑ CP | ☑ DISK

$$Y_{it}=\alpha+\beta_1(X_{it}-\bar{X}_i)+\beta_2\bar{X}_i+\beta_2Z_i+u_i+\varepsilon_{it}$$

where subscript i represents institutions and subscript t represents the time points. The time-varying independent variables are represented by X_{it}, the mean of the time-varying variables is $\bar{X}_i$, and time invariant variables are represented by Z_i. The unit-specific error term is u_i and the classical error term is ε_{it}. The model decomposes X_{it} into a within-institution component ($X_{it}-\bar{X}_i$), that is the equivalent of a fixed effects coefficient, and a between-institution component ($\bar{X}_i$) which is the potentially biased. We ran the analysis using Stata 13.1.

Results

Output Growth

The period 1980–2010 was one of steady and impressive growth in U.S. scientific research output as measured by research expenditures, research publications, and citations (see Figs. 1, 2, 3). Total research expenditures for the institutional sample grew in 2010 dollars from about \$4.4 billion in 1979 to \$46.9 billion in 2010, a 964% increase. Growth of R&D expenditures was evident in every decile during each time period measured. Research publications grew from about 191,000 in 1979 to about 555,000 in 2010, a 190 percentage increase over the period, and again growth was evident in every decile during each time period measured. Citations grew from 4.3 million in 1979 to 10.7 million in 2005, a 146% increase. Here, too, increases were evident in every decile during each time period measured.[11]

The great majority of the individual campuses in the sample increased their output over each decade studied.[12] Only 23 of the 188 sample institutions reporting data throughout the period (12.2%) experienced declines in any one of the three decades, and only one of these institutions experienced declines over two decades. Only eight of the sample institutions (4.3%) experienced declines in constant-dollar

[11] Growth should not be equated uncritically with proportionate increases in quality or significance of research. As universities and government agencies have begun to measure publication and citation outputs more regularly, pressures have increased to adopt distorting publication tactics, such as cutting up larger and higher quality papers into small text units, a practice known "salami publishing" or "least publishable units" (Fanelli 2010), as well as text recycling in multiple publications, also known as "self-plagiarism" (Necker 2014). On competitive pressures as a source of decline in scholarly reading practices, see also Abbott (2016). Similarly, it is possible to manipulate citations through "citation rings" in which inter-connected individuals make tacit agreements to boost each other's careers through co-citation. Publications and citations remain the best measures of scientific outputs, but these adaptations to competitive pressures should be kept in mind as partial explanations for output growth.

[12] We began this analysis in 1979–1980 and examined changes in R&D expenditures and publications in end years of the following decades 1989–1990, 1999–2000, and 2009–2010. For citations, we examined changes in 1989–1990 and 1999–2000 only because of foreshortened period for publications from 2010 have had only six years to accumulate citations, as compared to publications published in the earlier years.

Journal : Small-ext 11024 | Dispatch : 12-7-2017 | Pages : 22
Article No. : 9330 | □ LE | □ TYPESET
MS Code : MINV-D-16-00068 | ☑ CP | ☑ DISK

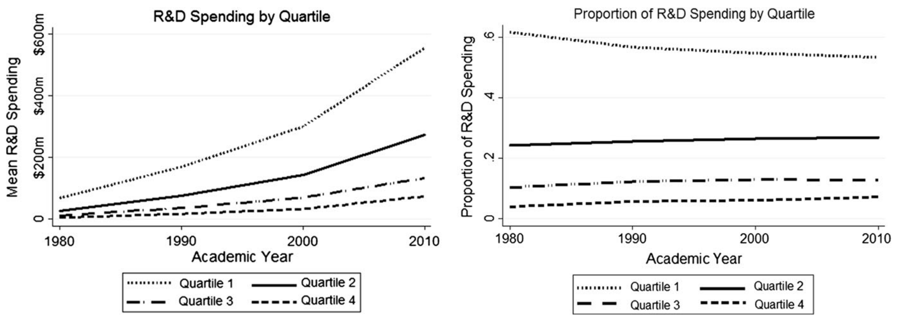

Fig. 1 R&D spending trends

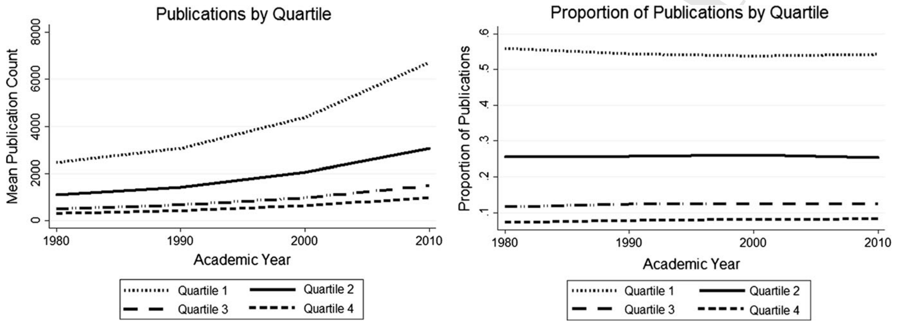

Fig. 2 Publication trends

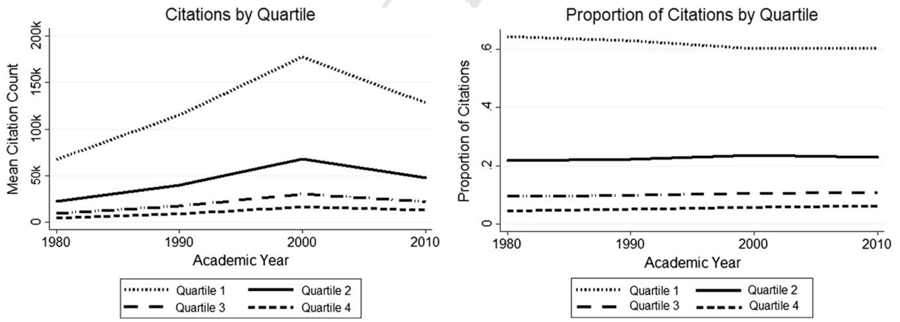

Fig. 3 Citation trends

R&D expenditures in any one of the three decades, and only ten of the institutions (5.3%) reported declines in citations in either of the two decades we were able to study in this analysis.[13]

[13] The gains in publications and citations also reflect the more than threefold growth of journals in the WoS database between 1972 and 2010 (Larsen and von Ins 2010). The growth in the number of journals catalogued is itself a function, in part, of a larger and more productive university labor force, capable of sustaining many more high-quality journals.

Table 1 GINI coefficients for publications and citations by year

	1980	1990	2000	2010
R&D spending	0.52	0.49	0.49	0.48
Publications	0.49	0.48	0.48	0.48
Citations	0.59	0.58	0.56	0.56

Inequality Trends

Changes in the Gini Coefficient

The Gini coefficients for total R&D expenditures, publications, and citations are reported in Table 1. Decreases in inequality were evident for all three indicators at the beginning of the period, 1980–1990, consistent with G&F's findings for total R&D expenditures. However, the Gini for R&D expenditures and publications remained constant or very nearly constant thereafter through 2010. (Gini continued to decline slightly only for citations through 2000). Thus, with the exception of the slight decline in inequality for citations, dispersion ceased to be the dominant trend by 1990 in this sample population, and the level of inequality reached in that year persisted through 2010, marking at least the temporary end to the period of slowly growing equality in R&D expenditures and research productivity outcomes.

Moreover, levels of inequality remained high in absolute terms throughout the period, particularly for citation counts. We can contrast the Gini coefficients reported in Table 1 to those common in studies of income distribution in economically developed countries. Gini coefficients for the distribution of income within 31 developed countries after taxes and transfers ran between 0.38 and 0.24 in 2010, according to Organisation for Economic Cooperation and Development (OECD) data (Desilver 2013), much lower than the Gini coefficients for scientific research output in U.S. research universities.

Changes in Interquartile Shares

As shown in Fig. 1, despite strong absolute gains throughout the period, first quartile R&D institutions showed a declining proportion of R&D spending over time with the other three quartiles showing very slight gains in share. By contrast, first-quartile shares of publications and citations remained steady (see Figs. 2, 3). Thus, G&F's emphasis on the growing prominence of second quartile institutions requires amendment for later periods; what we see over time is a steady increase in funds available for R&D on all levels, and very slight gains in share for institutions in the second through fourth quartiles in initial rank. The impressive system-wide gains in publications and citations, however, had virtually no effect on interquartile shares in terms of institutions.

Journal : Small-ext 11024 | Dispatch : 12-7-2017 | Pages : 22
Article No. : 9330 | □ LE | □ TYPESET
MS Code : MINV-D-16-00068 | ☑ CP | ☑ DISK

Inter-Decile Mobility

We found somewhat more mobility for R&D expenditures than for either publications or citations, but nevertheless more than 70% of the top decile institutions in R&D expenditures remained stable throughout the study period. For publication and citation counts, stability was pronounced in the top two deciles, with more than 80% of the membership of the top two deciles remaining constant from decade to decade. Stability was also evident in the bottom decile with more than 70% of the membership at the bottom remaining constant from decade to decade.

In R&D expenditures, publications, and citations, the top two deciles were composed of nearly equal numbers of private and public institutions. Among the privates, Harvard University, Stanford University, the Massachusetts Institute of Technology, Yale University, Cornell University, the University of Pennsylvania, Columbia University, Johns Hopkins University, Washington University-St. Louis, and Northwestern University were consistently ranked in the top two deciles across each of the measures and all three decades. Among the publics, five University of California campuses (UCLA, UC Berkeley, UC San Diego, UC San Francisco, and UC Davis), and six "Big Ten" campuses (the University of Wisconsin, the University of Michigan, the University of Minnesota, the University of Illinois, Ohio State University, Pennsylvania State University) were consistently ranked in the top two deciles across each of the measures and all three decades, together with two other flagship state universities (the University of Washington-Seattle and the University of Colorado-Boulder). A few other privates (the University of Southern California, California Institute of Technology, the University of Chicago), and several other publics (the University of Pittsburgh, the University of North Carolina-Chapel Hill, the University of Texas-Austin, Rutgers University, and the University of Florida) very nearly reached this level of high and consistent ranking in the top two deciles.[14]

We found more short-range mobility in the middle of the stratification structure, and again mobility was more common in R&D expenditures than in publications or citations. We examined 30 decile-decade categories (i.e., ten deciles times three decades). For R&D expenditures, we found that more than half of the members changed deciles from one decade to the next in 17 of the 30 categories. By contrast, for publications, we found that more than half of the members changed deciles from decade to decade in just eight of the 30 categories, and, for citations, more than half of the members changed deciles from decade to decade in just seven of the 30 categories. Clearly, considerable short-range mobility exists in the broad mid-ranks

[14] We found a similar level of stability at the bottom of the hierarchy; approximately 20 universities consistently scored low across each of the measures and all four decades. These included several regional campuses (the University of South Alabama, the University of North Dakota-Grand Forks, the University of Alabama-Huntsville, and the University of North Texas), two California campuses more often thought of as teaching institutions (San Diego State University and San Jose State University), three former liberal arts colleges (the College of William and Mary, Ohio University, and Old Dominion), several struggling science and engineering oriented universities (the Missouri University of Science and Technology, the Tennessee Technological University, the State University of New York College of Environmental Science, and the New Mexico Institute of Mining and Technology), and two minority-serving institutions (Florida A&M and the University of Puerto Rico).

Journal : Small-ext 11024 | Dispatch : 12-7-2017 | Pages : 22
Article No. : 9330 | □ LE | □ TYPESET
MS Code : MINV-D-16-00068 | ☑ CP | ☑ DISK

of the U.S. system of research universities, but even short-range mobility is limited in the cases of publications and citations.

Only a small number of institutions rose or fell by *more than one decile* over the 30-year period, the measure we have used for long-range mobility, and again we found fewer of these highly mobile institutions in the publications and citation count data than in R&D expenditures data. In R&D expenditures, slightly more than 20% of the sample moved up or down more than one decile over the 30-year period. In the publications rankings, 14% changed rank by more than one decile, and this level of mobility in the citation count ranks was still more restricted: only 12% of the total changed ranks by more than one decile over the period.

Ambitious research institutions are interested only in upward mobility, and it is consequently notable that only 8% of institutions experienced upward mobility of more than one decile during the 30-year period in publication count rankings, and only 7% experienced this level of upward mobility in R&D spending or citation count rankings. These findings indicate that long-range upward mobility was not a prominent feature of the system of scientific production in American research universities during the study period.[15]

Regression Analysis

Initial and continuing institutional investments in R&D were strongly associated with publication and citation counts. As shown in Table 2, R&D quartile rank at the beginning of the period was a very important predictor of both publication and citation counts, net of covariates. In addition, the analysis reveals a cleavage between high R&D spending institutions and more modest spenders. First and second quartile R&D institutions produced significantly more research and citations throughout the period than the reference group, fourth quartile institutions, and the point estimates for third quartile institutions were insignificant.

Results for financial strength showed mixed results. Expressed as an independent variable, it is negative and shows significant association only with citations, net of covariates. Full-time faculty fits a similar pattern, negative and significant only for citations. The interaction term *student subsidy x full-time faculty*, however, is

[15] Upwardly-mobile campuses included Emory University (5th to 2nd decile in publications and citations), Arizona State University (5th to 3rd decile in publications; 6th to 4th decile in citations), the Georgia Institute of Technology (7th to 4th decile in publications and citations), and the University of South Florida (7th to 5th decile in publications and citations). In addition, the mobility opportunities of free-standing medical colleges were high during the study period in which the budgets of the National Institutes of Health were consistently three to five times larger than that of the National Science Foundation (AAAS 2016). Several of them, such as the University of Texas M.D. Anderson School of Medicine (6th to 3rd decile in publications; 5th to 2nd decile in citations), the Baylor College of Medicine (4th to 2nd decile in publications; 5th to 3rd decile in citations), and the Icahn School of Medicine at Mt. Sinai Hospital (4th to 3rd decile in citations) were among those experiencing inter-decile upward mobility during the period. By contrast, the University of Oregon (4th to 8th decile in publications; 3rd to 7th decile in citations), Temple University (4th to 6th decile in publications and citations), Rockefeller University (6th to 8th decile in publications; 2nd to 5th decile in citations), Brandeis University (7th to 9th decile in publications; 5th to 8th decile in citations), and Howard University (8th to 10th decile in publications and citations) were among the institutions experiencing notable downward mobility during the period at the institutional level.

Journal : Small-ext 11024 Dispatch : 12-7-2017 Pages : 22
Article No. : 9330 □ LE □ TYPESET
MS Code : MINV-D-16-00068 ☑ CP ☑ DISK

Table 2 Regression

	Publications[b,c]	Citations[a,b,c]
Quartile 1 Institutions (1979)[d]	0.89**	1.14**
	(0.28)	(0.41)
Quartile 2 Institutions (1979)[d]	0.52**	0.67*
	(0.19)	(0.29)
Quartile 3 Institutions (1979)[d]	0.11	0.21
	(0.20)	(0.30)
Student subsidy[b]	−0.09	−0.14*
	(0.06)	(0.06)
Full-time faculty[e]	−0.23	−0.45
	(0.13)	(0.15)
Student subsidy × Full-time faculty	0.01*	0.02*
	(0.01)	(0.01)
Institutional RD[b,d]	−0.00	0.01
	(0.01)	(0.01)
Private, Nonprofit[e]	0.47***	0.78***
	(0.08)	(0.12)
Has a medical school[e]	0.14	0.20
	(0.09)	(0.13)
Is a medical school[e]	0.00	0.03
	(0.29)	(0.47)
Panel year	0.04***	0.04***
	(0.00)	(0.00)
System reporting[e]	−0.26**	−0.28*
	(0.09)	(0.11)
Intercept	−86.32***	90.50***
	(4.97)	(9.46)
R-Squared within	0.46	0.24
N	870	696

Standard errors in parentheses; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

[a] Citations model includes years 1990–2005

[b] Logged in preparation for the regressions

[c] Thomson Reuters Web of Science

[d] National Science Foundation Survey of Research and Development Expenditures at Universities and Colleges/Higher Education Research and Development Survey, made available by the National Center for Science and Engineering Statistics (NCSES)

[e] Delta Cost Project, The American Institutes for Research

positive and significant for both publications and citations, meaning that as institutions gain in financial means, faculty tend to produce more publications and citations. Continuing investments are represented by institutional R&D expenditures. This variable was not significant in our model either for publications or citation counts.

Journal : Small-ext 11024 Dispatch : 12-7-2017 Pages : 22
Article No. : 9330 □ LE □ TYPESET
MS Code : MINV-D-16-00068 ☑ CP ☑ DISK

Net of covariates, the coefficient for private institutions showed a strong significant association for both publications and citations. Institutions with medical schools and free-standing medical schools were both nonsignificant. The latter findings are surprising, given that frequency data showed that free-standing medical schools (and health sciences universities) were among the most upwardly mobile institutions during the period. However, the regressions suggest that the variation associated with medical schools can be explained by other variables in the model.[16]

One of the control variables, academic year, showed strong net positive associations with publication and citation counts. This finding testifies to the steady upward growth of scientific productivity in the great majority of the institutions over time, as reflected also in Figs. 1, 2 and 3. Net of covariates, system reporting was negative and significant, indicating that system reporting did not inflate the output of main campuses reporting as a part of their state systems.

System Change Due to Entrances and Exits

Our study is limited by its focus on a stable set of institutions identified by G&F as the leading research institutions in 1979. While this is necessary for a longitudinal study of the type we have conducted, a more comprehensive treatment of growth, inequality, and mobility in academic science would need to take into account the fact that membership in the research system has a dynamic quality resulting from the entrance of new institutions into the system and the departure of institutions that no longer produce enough research to count as among the top research universities.

We began to explore the consequences for the system produced by exits and entrances by comparing the current top 200 research universities, as measured by R&D expenditures, to the G&F identified population from 1979. We found 25 new entrants to the top 200 and 19 from the G&F sample that were no longer in the top 200 in 2010. Both more recent entrants into the top 200 R&D list and those that no longer engage in enough R&D spending to be classified in the top 200 were clustered at the bottom of the academic science hierarchy. The vast majority of recent entrants on the 2010 list (i.e., those not included by G&F) were located in the bottom three deciles, and only four of the institutions were located in the mid-range of deciles. Gini coefficients also indicated that levels of inequality were as high or higher for the current top 200 as they were in the constant sample. Ginis for R&D expenditures were the same for the two sets (0.48). We found somewhat more inequality on publication counts for the 2010 top 200 set than for the constant set of institutions drawn from G&F's sample (0.58 as compared to 0.48), and marginally higher inequality as well on citation counts (0.59 as compared to 0.56).

[16] Unreported between coefficients were significant; however, it is unclear whether this is due to diversity of institutional contexts, or whether it is due to omitted variable bias.

Journal : Small-ext 11024 | Dispatch : 12-7-2017 | Pages : 22
Article No. : 9330 | □ LE | □ TYPESET
MS Code : MINV-D-16-00068 | ☑ CP | ☑ DISK

Discussion

Our analyses reveal an increasingly productive system of U.S. research universities, with very robust growth rates throughout the period on all three measures examined. Moreover, the great majority of the 188 individual institutions in our longitudinal sample also increased their research output steadily throughout the period. These robust growth patterns co-existed with a stable and high level of inequality, as measured by Gini coefficients and inter-quartile shares. The dispersion of research spending observed by G&F in the 1980s leveled off after 1990, as did dispersion in publications and citations. Considerable short-range mobility existed in the system, but mobility of more than one decile over the 30-year period was rare. Competition for place may have contributed to the overall productivity of the system, even if it failed to produce many universities whose positions improved or deteriorated greatly over time.[17]

Our findings do not support either the model of increasing concentration or the model of continuing dispersion of research contributions. We find some support in the data for G&F's finding of a declining first quartile and rising second quartile of research institutions. However, these trends are most prominent in the 1980s (the period of G&F's analysis), mixed through the 1990s, and reversed in the 2000s so that first quartile institutions begin to gain relative share again (see Figs. 1, 2, 3). The findings on Gini coefficients are consistent with this pattern (see Table 1).

Our findings suggest a mature, highly unequal system with considerable opportunity for short-range upward mobility in the broad middle ranks but very limited opportunity for long-range mobility. Highly cited research continues to be concentrated in a set of approximately 30 institutions that were also among the most productive institutions in 1979. Only a few institutions have joined the top stratum since 1979. More flux is evident below this top stratum. Moreover, new entrants largely replace exiting institutions at the bottom of the hierarchy. These findings suggest that university administrators who promote short-term mobility targets or invest heavily in novel strategies for moving up in the publication or citation rankings are likely to be disappointed.

The top institutions have the resources and prestige to recruit top scientists and scholars.[18] This recruitment power should lead to increasing concentration. An offsetting factor may be the high-quality of new doctorates produced by the country's leading graduate programs. Because opportunities are, by definition, limited at the top, a large proportion of high-quality individuals may begin and continue their careers at lower-ranked institutions, where they have sufficient resources to pursue productive careers. We emphasize that our data do not bear directly on these questions, and future research will be necessary to explore these and other reasons for the impressive levels of stable inequality we found.

[17] A case can be made that continued dispersion would have encouraged a still more productive system, but the obvious counterfactuals to prove such a case are missing. Dispersion leveled off after 1990, but the rate of system productivity, as measured by publications and citations, nevertheless continued to grow robustly.

[18] For a penetrating analysis of these processes in one discipline, see Burris (2004).

Journal : Small-ext 11024	Dispatch : 12-7-2017	Pages : 22
Article No. : 9330	□ LE	□ TYPESET
MS Code : MINV-D-16-00068	☑ CP	☑ DISK

The study provides support for the Hicks and Katz (2011) hypothesis that R&D expenditures are more equally distributed than measures of scientific output, such as publications and citations, would predict. It remains to be seen whether this disjuncture is due, as Hicks and Katz argue, primarily to politically driven preferences among funders for a broader distribution of resources, or to other factors, such as differential levels of commitment among institutions to entrepreneurial activities that bypass peer review. In either event, the disjuncture between inputs and outputs injects somewhat more opportunity into the system than we could expect from a resource environment in which funding was more completely aligned with patterns of demonstrated scientific contribution, as represented by WoS publications and citations.

Within the system, initial investments in research were positively and significantly associated with higher levels of research contribution, as measured by publications and citations. In addition, faculty were shown to be more productive during the period in wealthier institutions where resources supporting their scholarship are more likely to be available. The patient, far-sighted application of resources toward accomplishment of the research mission is a necessary and perhaps obvious influence on scientific research productivity, but one that few institutions have had the latitude or determination to enact rigorously. Institutions that have had such practices in place longer tend to be in a better position to support faculty scientific productivity at the highest levels, as demonstrated by the significant interaction between institutional wealth and faculty productivity in both models. Nor do all universities have the historical engagement or ongoing financial resources to invest heavily in the research enterprise, including through renewal of laboratory facilities and equipment, on-campus research support services, and the maintenance of established pro-research practices, such as the use of post-doctoral scholars, lower teaching loads for research-productive scholars, and the availability of course remissions. Our analyses indicate that private research universities are more committed to such investments, independent of their initial position at the beginning of the time period.

Acknowledgments We would like to thank Michaela Curran and Matthew C. Mahutga for consulting on the statistical modeling used in this paper. We would like to thank the anonymous reviewers for comments that improved the quality of the paper.

Appendix

Descriptive statistics

Variable	N. Obs.	Mean	SD	Min.	Max.	Skewness
Dependent variables						
Publications[b]	870	2,150	2,303	0	25,656	3.06
Citations[b]	870	61,514	83,233	0	918,119	4.08
Indep. variables						
R&D quartiles (1979)[c]	870	2.50	1.12	1.00	3.00	0.00
Full-time faculty[d]	870	1,456	1,161	23	11,585	2.53
Institutional R&D[a,c]	870	29,800,000	34,600,000	0	274,000,000	2.11
Student subsidy[a,d]	870	152,000,000	222,000,000	0	2,830,000,000	5.05
Private[d]	870	0.32	0.47	0.00	1.00	0.79
Medical school[d]	870	0.68	0.64	0.00	2.00	0.41
Academic year	870	2000	7	1990	2010	0
System reporting[d]	870	0.25	0.43	0.00	1.00	1.17

[a] Logged in preparation for the regressions

[b] Thomson Reuters Web of Science

[c] National Science Foundation Survey of Research and Development Expenditures at Universities and Colleges/Higher Education Research and Development Survey, made available by the National Center for Science and Engineering Statistics (NCSES)

[d] Delta Cost Project, The American Institutes for Research

References

Abbott, Andrew. 2016. The demography of scholarly reading. *American Sociologist* 47: 302–318.

Adams, James D., Grant C. Black, J. Roger Clemmons, and Paula E. Stephan. 2005. Scientific teams and institutional collaborations: Evidence for U.S. universities, 1981–1999. *Research Policy* 34: 259–285.

Adams, James D., and Zvi Griliches. 1998. Research productivity in a system of universities. *Annales d'Economic et Statistique* 49(50): 127–162.

Allison, Paul. 2009. *Fixed effects regression models: 160 (Quantitative Methods in the Social Sciences) 07–160*. Los Angeles: SAGE Publications.

American Institutes of Research (AIR). 2014. *Delta cost study database*. Washington, DC: AIR.

American Association of University Professors (AAUP). 2015. *Busting the myths: The annual report on the economic status of the profession*. https://www.aaup.org/reports-publications/2014-15salarysurvey/.

American Association for the Advancement of Science (AAAS). 2016. *Trends in research by agency, FY 1976–2016*. Washington, DC: AAAS.

Burris, Val. 2004. The academic caste system: Prestige hierarchies in Ph.D. exchange networks. *American Sociological Review* 69: 239–264.

Charlton, Bruce G., and Peter Andras. 2007. Evaluating universities using simple scientometric research output metrics: Total citation counts per university for a retrospective seven-year rolling sample. *Science and Public Policy* 34: 555–563.

Desilver, Drew. 2013. Global inequality: How the U.S. compares. *Pew Research Center Fact Tank* (December 19).

Dundar, Halil, and Darrell R. Lewis. 1998. Determinants of research productivity in higher education. *Research in Higher Education* 39(6): 607–631.

Fanelli, Danielle. 2010. Do pressures to publish increase scientists' bias? An empirical support from U.S. States data. *PLOS One* 5. doi: 10.1371/journal.pone.0010271. Accessed 04 July 2017.

Journal : **Small-ext 11024**	Dispatch : **12-7-2017**	Pages : **22**
Article No. : **9330**	□ LE	□ TYPESET
MS Code : **MINV-D-16-00068**	☑ CP	☑ DISK

Geiger, Roger L., and Irwin Feller. 1995. The dispersion of academic research in the 1980s. *Journal of Higher Education* 66: 336–360.

Gibbons, Michael, Camille Limoges, Helga Nowotny, Simon Schwartzman, Peter Scott, and Martin Trow. 1994. *The new production of knowledge: The dynamics of science and research in contemporary societies*. Thousand Oaks: Sage Publications.

Halaby, Charles N. 2004. Panel models in sociological research: Theory into practice. *Annual Review of Sociology* 30: 507–544.

Halffman, Willem, and Loet Leydesdorff. 2010. Is inequality among universities increasing? Gini coefficients and the elusive rise of elite universities. *Minerva* 48: 55–72.

Hicks, Diana. 2012. Performance-based university research funding systems. *Research Policy* 41: 251–261.

Hicks, Diana, and J. Sylvan Katz. 2011. Equity and excellence in research funding. *Minerva* 49: 137–151.

Jaquette, Ozan, and Edna Parra. 2016. The Problem with the Delta Cost Project Database. *Research in Higher Education* 57(5): 630–651.

Javitz, Harold. 2006. *Statistical analysis of publication trends in U.S. universities*. Washington, DC: SRI International.

King, David A. 2004. The scientific wealth of nations. *Nature* 430: 311–316.

Larsen, Peder Olesen, and Markus von Ins. 2010. The rate of growth in scientific publication and the decline in coverage provided by Science Citation Index. *Scientometrics* 84(3): 575–603.

McNamee, Stephen J., and Cecil L. Willis. 1994. Stratification in science: A comparison of publication patterns in four disciplines. *Science Communication* 15: 396–416.

Merton, Robert K. 1968. The Matthew Effect in science: The reward and communication systems of science reconsidered. *Science* 59(3810): 56–63.

National Science Board. 2014. *Science and engineering indicators 2014*. Washington, DC: National Science Foundation (NSB 14-01).

National Science Foundation (NSF). 2015. *National center for science and engineering statistics higher education R&D survey*. Washington, DC: NSF.

Necker, Sarah. 2014. Scientific misbehavior in economics. *Research Policy* 43: 1747–1759.

Owen-Smith, Jason. 2003. From separate systems to hybrid order: Accumulative advantage across public and private science at Research One Universities. *Research Policy* 32: 1081–1104.

Office of Technology Assessment. 1991. *Federally funded research: Decision for a decade*. Washington DC: U.S. Government Printing Office.

Pouris, Anastassios. 2007. The international performance of the South African academic institutions: A citation assessment. *Higher Education* 54: 501–509.

Rogers, W.H. 1993. Regression standard errors in clustered samples. *Stata Technical Bulletin* 13: 19–23. (Reprinted in Stata Technical Bulletin Reprints, vol. 3, 88–94.).

Rosenzweig, Robert. 1992. Balancing national research capacity with its support. In *Science and Technology Policy Yearbook 1992*, eds. Stephen D. Nelson, Kathleen M. Gramp, and Albert H. Teich, 205–208. Washington DC: American Association for the Advancement of Science.

Times Higher Education. 2011. *Citation averages, 2000–2010, by fields and years*. https://www.timeshighereducation.com/news/citation-averages-2000-2010-by-fields-and-years/415643.article/. Accessed 04 July 2017.

Toutkoushian, Robert K., Stephen R. Porter, Cherry Danielson, and Paula R. Hollis. 2003. Using publication counts to measure an institution's research productivity. *Research in Higher Education* 44: 121–148.

U.S. House of Representatives, House Committee on Science, Space, and Technology. 1992. *Report on the task force on the health of research*. Washington DC: U.S. Government Printing Office.

U.S. News & World Report (USNWR). 2015 (Sept. 9). *America's best colleges*. www.usnwr.com/best-colleges/.

Ville, Simon, Abbas Valadkhani, and Martin O'Brien. 2006. Distribution of research performance across Australian universities, 1992–2003, and its implications for building diversity. *Australian Economic Papers* 45: 343–361.

Winston, Gordon C. 1999. Subsidies, hierarchy and peers: The awkward economics of higher education. *Journal of Economic Perspectives* 13: 13–36.

Winston, Gordon C. 2004. Differentiation among U.S. colleges and universities. *Review of Industrial Organization* 24: 331–354.

Ziman, John. 1994. *Prometheus bound: Science in a dynamic steady state*. Cambridge: Cambridge University Press.

Journal : **Small-ext 11024**	Dispatch : **12-7-2017**	Pages : **22**
Article No. : **9330**	□ LE	□ TYPESET
MS Code : **MINV-D-16-00068**	☑ CP	☑ DISK