Building and Sustaining a Diverse Faculty: Implications for Faculty Advancement and Reward Systems

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Suggested Readings
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PERSPECTIVE

Rescuing US biomedical research from its systemic flaws

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The long-held but erroneous assumption of never-ending rapid growth in biomedical science has created an unsustainable hypercompetitive system that is discouraging even the most outstanding prospective students from entering our profession—and making it difficult for seasoned investigators to produce their best work. This is a recipe for long-term decline, and the problems cannot be solved with simplistic approaches. Instead, it is time to confront the dangers at hand and rethink some fundamental features of the US biomedical research ecosystem.

graduate education | postdoctoral education | federal funding | peer review

By many measures, the biological and medical sciences are in a golden age. That fact, which we celebrate, makes it all the more difficult to acknowledge that the current system contains systemic flaws that are threatening its future. A central flaw is the long-held assumption that the enterprise will constantly expand. As a result, there is now a severe imbalance between the dollars available for research and the still-growing scientific community in the United States. This imbalance has created a hypercompetitive atmosphere in which scientific productivity is reduced and promising careers are threatened.

In retrospect, the strains have been building for some time, but it has been difficult to recognize them in the midst of so much success. During the last half century, biomedical scientists have discovered many of the fundamental principles that instruct cell behavior in both health and disease, providing a framework for exploring biological systems in great depth: the genetic code, the sequence and organization of many genomes, the cell's growth and division cycle, and the molecules that mediate cell signaling. Many diseases—infectious, hereditary, neoplastic, circulatory, and metabolic—are now approached and often prevented, controlled, or cured with measures based on these and other discoveries.

The American public rightly takes pride in this and has generously supported research efforts through the National Institutes of Health (NIH) and numerous other federal agencies, foundations, advocacy groups, and academic institutions. In return, the remarkable outpouring of innovative research from American laboratories—high-throughput DNA sequencing, sophisticated imaging, structural biology, designer chemistry, and computational biology—has led to impressive advances in medicine and fueled a vibrant pharmaceutical and biotechnology sector.

In the context of such progress, it is remarkable that even the most successful scientists and most promising trainees are increasingly pessimistic about the future of their chosen career. Based on extensive observations and discussions, we believe that these concerns are justified and that the biomedical research enterprise in the United States is on an unsustainable path. In this article, we describe how this situation arose and propose some possible remedies.

Source of the Dilemma

We believe that the root cause of the widespread malaise is a longstanding assumption that the biomedical research system in the United States will expand indefinitely at a substantial rate. We are now faced with the stark realization that this is not the case. Over the last decade, the expansion has stalled and even reversed.

The idea that the research enterprise would expand forever was adopted after World War II, as the numbers and sizes of universities grew to meet the economy's need for more graduates and as the tenets of Vannevar Bush's "Science: The Endless Frontier" encouraged the expansion of federal budgets for research (1). Growth persisted with the coming of age of the baby boom generation in the late 1960s and 1970s and a vibrant US economy.

However, eventually, beginning around 1990 and worsening after 2003, when a rapid doubling of the NIH budget ended, the demands for research dollars grew much faster than the supply. The demands were fueled in large part by incentives for institutional expansion, by the rapid growth of the scientific workforce, and by rising costs of research. Further slowdowns in federal funding, caused by the Great Recession of 2008 and by the budget sequestration that followed in 2013, have significantly exacerbated the problem. (Today, the resources available to the NIH are estimated to be at least 25% less in constant dollars than they were in 2003.) The consequences of this imbalance include dramatic declines in success rates for NIH grant applicants and diminished time for scientists to think and perform productive work.

The mismatch between supply and demand can be partly laid at the feet of the discipline's Malthusian traditions. The great majority of biomedical research is conducted by aspiring trainees: by graduate students and postdoctoral fellows. As a result, most successful biomedical scientists train far more scientists than are needed to replace him- or herself; in the aggregate, the training pipeline produces more scientists than relevant positions in academia, government, and the private sector are capable of absorbing. Consequently a growing number of PhDs are in jobs that do not take advantage of the taxpayers' investment in their lengthy education

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(2). Fundamentally, the current system is in perpetual disequilibrium, because it will inevitably generate an ever-increasing supply of scientists vying for a finite set of research resources and employment opportunities. The resulting strains have diminished the attraction of our profession for many scientists—novice and experienced alike.

Damaging Effects of Hypercompetition

Competition in pursuit of experimental objectives has always been a part of the scientific enterprise, and it can have positive effects. However, hypercompetition for the resources and positions that are required to conduct science suppresses the creativity, cooperation, risk-taking, and original thinking required to make fundamental discoveries.

Now that the percentage of NIH grant applications that can be funded has fallen from around 30% into the low teens, biomedical scientists are spending far too much of their time writing and revising grant applications and far too little thinking about science and conducting experiments. The low success rates have induced conservative, short-term thinking in applicants, reviewers, and funders. The system now favors those who can guarantee results rather than those with potentially path-breaking ideas that, by definition, cannot promise success. Young investigators are discouraged from departing too far from their postdoctoral work, when they should instead be posing new questions and inventing new approaches. Seasoned investigators are inclined to stick to their tried-and-true formulas for success rather than explore new fields.

One manifestation of this shift to short-term thinking is the inflated value that is now accorded to studies that claim a close link to medical practice. Human biology has always been a central part of the US biomedical effort. However, only recently has the term "translational research" been widely, if unofficially, used as a criterion for evaluation. Overvaluing translational research is detracting from an equivalent appreciation of fundamental research of broad applicability, without obvious connections to medicine. Many surprising discoveries, powerful research tools, and important medical benefits have arisen from efforts to decipher complex biological phenomena in model organisms. In a climate that discourages such work by emphasizing short-term goals, scientific progress will inevitably be slowed, and revolutionary findings will be deferred (3).

Traditional standards for the practice of science are also threatened in this environment. Publishing scientific reports, especially in the most prestigious journals, has become increasingly difficult, as competition increases and reviewers and editors demand more and more from each paper. Long appendixes that contain the bulk of the experimental results have become the norm for many journals and accepted practice for most scientists. As competition for jobs and promotions increases, the inflated value given to publishing in a small number of so-called "high impact" journals has put pressure on authors to rush into print, cut corners, exaggerate their findings, and overstate the significance of their work. Such publication practices, abetted by the hypercompetitive grant system and job market, are changing the atmosphere in many laboratories in disturbing ways. The recent worrisome reports of substantial numbers of research publications whose results cannot be replicated are likely symptoms of today's highly pressured environment for research (4–6). If through sloppiness, error, or exaggeration, the scientific community loses the public's trust in the integrity of its work, it cannot expect to maintain public support for science.

Crippling Demands on a Scientist's Time

The development of original ideas that lead to important scientific discoveries takes time for thinking, reading, and talking with peers. Today, time for reflection is a disappearing luxury for the scientific community. In addition to writing and revising grant applications and papers, scientists now contend with expanding regulatory requirements and government reporting on issues such as animal welfare, radiation safety, and human subjects protection. Although these are important aspects of running a safe and ethically grounded laboratory, these administrative tasks are taking up an ever-increasing fraction of the day and present serious obstacles to concentration on the scientific mission itself.

Time pressures are also affecting the quality of peer review, an essential element of a healthy ecosystem for science. Investigators often lack the time to review manuscripts for journals, leaving these tasks to their students and fellows who may lack the experience needed to appreciate the broader context of the work and the provisional nature of truly original findings. Professional editors are increasingly serving in roles played in the past by working scientists and can undermine the enterprise when they base judgments about publication on newsworthiness rather than scientific quality.

The peer review of applications for research grants has also been affected. Historically, study sections that review applications were composed largely of highly respected leaders in the field, and there was widespread trust in the fairness of the system. Today it is less common for senior scientists to serve. Either they are not asked or, when asked, it is more difficult to persuade them to participate because of very low success rates, difficulties of choosing among highly meritorious proposals, and the perception that the quality of evaluation has declined.

Supporting the Next Generation of Scientists

There is a no more worrisome consequence of the hypercompetitive culture of biomedical science than the pall it is casting on early careers of graduate students, postdoctoral fellows, and young investigators. A recent study commissioned by NIH Director Francis Collins documented the rapid growth in the number of biomedical PhDs and postdoctoral fellows trained in the United States, driven most recently by the doubling of the NIH budget that ended a decade ago (2). As those trainees complete their studies, they have come face to face with slowdowns or contractions in the employment sectors—academia, government, and the pharmaceutical and biotech industries—that could and should benefit from their long years of training. This has led to an extended occupancy of training positions, coupled to greatly increased expectations from prospective employers for prior productivity.

Even after they have landed a research position in academia or research institutes, new investigators wait an average of 4–5 y to receive federal funding for their work compared with 1 y in 1980 (2). Two stark statistics tell much of the tale—the average age at which PhD recipients assume their first tenure-track job is 37 y, and they are approaching 42 y when they are awarded their first NIH grant. In 1980, 16% of NIH grant recipients were 36 y of age or younger; today that number is 3% (2). It is no surprise that extraordinarily well-trained and successful young scientists are opting out of academic science in greater and greater numbers; not because they find other opportunities so much more attractive, but because they are discouraged by the nature of their future life in academia.

From the early 1990s, every labor economist who has studied the pipeline for the biomedical workforce has proclaimed it to be broken (2, 7–12). However, little has been done to reform the system, primarily because it continues to benefit more established and hence more influential scientists and because it has undoubtedly produced great science. Economists point out that many labor markets experience expansions and contractions, but biomedical science does not respond to classic market forces. As the demographer

Michael Teitelbaum has observed (9), lower employment prospects for future scientists would normally be expected to lead to a decline in graduate school applicants, as well as to a contraction in the system.

In biomedical research, this does not happen, in part because of a large influx of foreign applicants (2) for whom the prospects in the United States are more attractive than what they face in their own countries, but also because the opportunities for discovering new knowledge and improving human health are inherently so appealing.

Perverse Incentives in Research Funding

The assumption that the biomedical research enterprise will expand continuously at a high rate has powerfully motivated the behavior of large academic medical centers (7–9). Salaries paid by grants are subject to indirect cost reimbursement, creating a strong incentive for universities to enlarge their faculties by seeking as much faculty salary support as possible on government grants. This has led to an enormous growth in "soft money" positions, with stagnation in the ranks of faculty who have institutional support. The government is also indirectly paying for the new buildings to house these scientists by allowing debt service on new construction to be included in its calculations of indirect cost recovery.

These are perverse incentives because they encourage grantee institutions to grow without making sufficient investments in their own faculty and facilities. As a result, thousands of US faculty members now compete intensely not only for research funds but also for their own salaries within a shrinking pool of dollars.

Recommendations for Change

To create a more sustainable enterprise—one that achieves the high goals to which both biomedical scientists and the public aspire—we propose several steps, some of which will need to be gradually implemented over a prolonged period (perhaps as long as 10 y).

Our broad objectives are threefold: (*i*) to advocate for predictable budgets for US funding agencies and for an altered composition of the research workforce, both with the aim of making the research environment sustainable; (*ii*) to rebalance the research portfolio by recognizing the inertia that favors large projects and by improving the peer review system so that more imaginative, long-term proposals are being funded and scientific careers can have a more stable course; and (*iii*) to encourage changes in governmental policies that now have the unintended consequence of promoting excessive, unsustainable growth of the US biomedical research enterprise.

Specific Recommendations

Planning for Predictable and Stable Funding of Science. In this paper, we focused on the structural aspects of the US biomedical enterprise that need attention in an era of limited resources rather than making the case for greater resources. Nevertheless, we strongly believe that increased funding would have great benefits in both the short and long run, that the remarkable opportunities in biomedical science justify enlarged budgets, and that vigorous arguments for such increases should be made. However, our current funding system has no built-in regulator, so budget increases are always rapidly absorbed and create a need for even greater increases.

In allocating federal funds for the research enterprise, greater emphasis should be placed on the predictability and stability of growth. We encourage Congressional appropriators and the executive branch to consider adding a 5-y projected fiscal plan to the current budgetary process. This plan would be updated each year, at the same time that annual appropriation bills are written. This modest addition to the present system, while not creating inflexible mandates, would acknowledge the need for long-term planning for measured growth of the nation's scientific enterprise.

Bringing the Biomedical Enterprise into Sustainable Equilibrium. The goal of the next set of recommendations is to gradually reduce the number of entrants into PhD training in biomedical science—producing a better alignment between the number of entrants and their future opportunities—and to alter the ratio of trainees to staff scientists in research groups. At the same time, we should do more to help transition outstanding young people with scientific training into a broad range of careers that can benefit from their abilities and education. Together those changes will lead to an enterprise that is both more flexible and sustainable.

Educating graduate students. For the last several decades, the numbers of graduate students pursuing careers in biomedical science have grown unchecked because trainees are overwhelmingly supported on research grants (2). In contrast, the number of students who rely on training grants and individual fellowships has remained constant for a long time.

To give federal agencies more control over the number of trainees and the quality of their training, we propose moving gradually to a system in which graduate students are supported with training grants and fellowships and not with research grants. Fellowships have the virtue of providing peer review of the student applicants, and training programs set high standards for selection of students and for the education they receive.

If this recommendation is adopted, it will be essential to change policies that now prohibit the funding of non-US citizens on training grants. Foreign students have contributed enormously to the vibrancy and success of US science, and their continuing contributions are critical to the future of science in the United States.

Broadening the career paths for young scientists. Graduate training in biomedical fields has historically functioned as an apprenticeship, in which students conduct original research with the expectation that they will replace their mentors. With the percentage of recent PhDs in academic positions falling to 20% (2), the training of graduate students needs to diversify to reflect the realities of the job market. A graduate education in the sciences produces individuals with broadly applicable skills in critical thinking and problem-solving, whose expertise could be invaluable in fields such as science policy and administration, the commerce of science, science writing, the law, and science education at all levels. Furthermore, recent surveys reveal that a substantial fraction of today's graduate students in the sciences are interested in pursuing nonresearch careers (13, 14). However, for the most part, neither the faculty nor the students are well enough informed about such careers. Nor are there clear pathways for entry. (One exception is the AAAS Science and Technology Fellowships, which for 40 y have allowed carefully selected scientists and engineers with advanced degrees to work in the US government in Washington, DC, for a year. Historically, approximately half of these Fellows have remained in policy positions, occupying critical positions that greatly benefit the nation. However, such opportunities number in the low hundreds each year, a small fraction of the 8,000 PhDs who graduate annually in the biological sciences alone.)

To make informed decisions, graduate students need opportunities to gain hands-on experience in appropriate career environments. We should aim for a future in which graduate students have opportunities to explore a variety of career paths, with only those seeking careers that demand additional research training taking up postdoctoral research positions. To that end, the NIH has recently announced a new program to encourage diversifying graduate education (15). Moreover, interdisciplinary MS degree programs that combine training in science with leadership, project management, teamwork, and communication skills match well with industry needs (11, 16) and should be expanded with federal support.

Training postdoctoral fellows. There are currently more than 40,000 postdoctoral fellows in the US biomedical research system, and the number has been increasing rapidly in recent years (2, 17). The position has become one in which young scientists spend a significant fraction of their most productive years while being paid salaries that are quite low considering their extensive education. On the one hand, these fellows are pursuing science full time without the distractions that often come with more permanent jobs. On the other hand, for most of them, the holding pattern postpones the time when they are able to explore their own ideas in independent careers.

We offer two suggestions intended to reduce the numbers of postdoctoral fellows and promote a more rapid transit through postdoctoral training:

i) Increase the compensation for all federally funded postdoctoral fellows, regardless of grant mechanisms. This would need to be done gradually over time, with the goal of reaching the compensation levels for staff scientists. This proposal would reduce the total number of fellows that the system could support and eliminate cost considerations when a laboratory head weighs the benefits of choosing between a postdoctoral fellow and a staff scientist (see next section).

ii) Limit the total number of years that a postdoctoral fellow may be supported by federal research grants. Beyond this limit, salaries would be required to rise to that of research staff scientists, as is already the case at some institutions.

Using staff scientists. Historically, staff scientists—usually MSc or PhD recipients who are no longer trainees—have been used sparingly in US research laboratories. Resistance to staff scientists has focused on the greater cost of salaries relative to graduate students and fellows and on the belief that permanent staff may be less creative and hardworking. These arguments ignore the fact that beginning graduate students and fellows are also costly because they often require considerable time to become highly productive.

We believe that staff scientists can and should play increasingly important roles in the biomedical workforce. Within individual laboratories, they can oversee the day-to-day work of the laboratory, taking on some of the administrative burdens that now tend to fall on the shoulders of the laboratory head; orient and train new members of the laboratory; manage large equipment and common facilities; and perform scientific projects independently or in collaboration with other members of the group. Within institutions, they can serve as leaders and technical experts in core laboratories serving multiple investigators and even multiple institutions.

We recommend increasing the ratio of permanent staff positions to trainee positions, both in individual laboratories and in core facilities that serve multiple laboratories. To succeed, universities will need employment policies that provide these individuals with attractive career paths, short of guaranteed employment. Also, granting agencies will need to recognize the value of longer-serving laboratory members. If adopted, this change would help to bring the system closer to equilibrium. There is precedent for such a policy in the intramural NIH research program, which employs many well-trained MSc and PhD graduates as staff scientists to conduct research.

Two of the likely consequences of these changes in graduate and postdoctoral training and employment of staff scientists will be an increase in the unit cost of research and a reduction in the average size of laboratories. We believe that the significant benefits—including brighter prospects for trainees, less pressure to obtain multiple grants to sustain a group's financial viability, increased incentives to collaborate, and more time for investigators to focus on their science—substantially outweigh the limitations.

Grant-Making That Improves Scientific Productivity. To increase support for the best science through federal grants, we recommend that funding agencies take several steps to improve the criteria and mechanisms used to evaluate candidates and their proposals. We also recommend a shift in the kinds of research grants offered. Also, to ensure the highest standards of excellence, we propose that objective outside reviews be commissioned at regular intervals to monitor both the value of established programs and the quality of agency implementations.

Improving the goals and mechanisms for scientific grants. In awarding research grants, recognition of originality is critical for achieving the goal of making scientific advances that promise long-term benefits to society. Providing resources to those scientists who are most likely to make important contributions over the course of their career is essential for the optimal use of research funds.

i) We recommend wider use of grant mechanisms that provide more stable support for outstanding investigators at various career stages, focusing as much (or more) on the overall quality of their science as on their proposed projects. The success of investigators supported by the Howard Hughes Medical Institute (18), which takes this approach, suggests that, with very careful screening by the appropriate reviewers (who must be outstanding scientists themselves), this can be an especially effective way to support and encourage excellent science. This approach is under active discussion among NIH leadership (6).

ii) Inertia and financial dependency favor continuing large research programs, so sunset provisions should be built into all new programs and orchestrated team efforts. To combat the tendency for fields to become parochial, agencies should develop funding mechanisms that encourage the growth of new fields, both by direct support for new science and by a rigorous regular evaluation of existing programs.

iii) Science agencies should significantly increase the numbers and kinds of awards that emphasize originality and risk-taking, especially in new areas of science, without requiring extensive preliminary results. This is particularly critical for beginning independent investigators, who should be encouraged to depart from the work that they carried out as trainees to investigate unexplored problems in new ways. Programs like the NIH Director's New Innovator Award (19) have been designed for this purpose, but there are far too few such awards to affect the way that young scientists currently plan their careers

iv) Agencies should also be sensitive to the total numbers of dollars granted to individual laboratories, recognizing that—although different research activities have different costs—at some point, returns per dollar diminish. For that reason, we applaud the recent decision by the NIH to examine grant portfolios carefully before increasing direct research support for a laboratory beyond one million dollars per year.

Improving evaluation criteria. The peer review panels that evaluate grant proposals require appropriate criteria to guide their work. To this end, we recommend the following:

i) The tools used to judge past performance should be sharpened to identify the strongest candidates for support. The qualitative aspects of each candidate's major scientific achievements should receive more emphasis than the numbers and venues of publications. Evaluation criteria should also put a higher priority on the quality, novelty, and long-term objectives of the project than on technical details.

ii) Review guidelines should be appropriately adjusted for young scientists to promote the funding of thoughtful proposals that reveal ingenuity and promise findings with potentially broad implications. The criteria used to evaluate the NIH Director's New Innovator Award set useful standards.

Strengthening grant review panels. Expert peer review depends on recruiting the most qualified scientists to carry it out.

i) The quality of review groups should be enhanced by taking advantage of the full range of talent in the scientific community. All current grant holders should be expected to serve on such groups if asked and not just once in a career. In addition, federal agencies should diminish the requirement for geographical representation that now limits the choice of panel members. These changes will allow funding agencies to recruit the best scientists of all ages and from all locations to perform this critical service for the scientific community.

ii) Those who plan and assemble review groups should broaden the range of scientific problems judged by each group and include a diversity of fields on each panel. Senior scientists with a wide appreciation for different fields can play important roles by counteracting the tendency of specialists to overvalue work in their own field. When review bodies become too insular, they risk becoming special interest groups for their subfield and may fail to encourage support of the most imaginative science.

Evaluating programs, policies, and their implementation. Even the best policies and processes—whether applied to scientific programs or to the review of applications—require periodic arms-length evaluations, especially in times of fiscal constraint. We urge agencies to continue and expand such evaluations, to make the findings publicly accessible, and to recognize the advantages of having them performed by groups that are independent of the agency being examined. The questions asked should include whether a particular program or policy is being well executed, how it might be improved, what types of data are needed to guide evaluation, and whether the goals might be better met in other ways.

Addressing Policies That Undermine Sustainability. Federal policies regarding indirect cost recovery have the advantage of providing support for facilities and administrative costs only after a merit-based peer review of research proposals. However, they have also enabled academic medical centers and other institutions to expand their faculties and facilities without making corresponding investments of their own, generating some of the perverse incentives discussed earlier.

We recommend that the US government develop a plan to revise these practices gradually over the next decade while providing a discrete timetable. Targets of policy change should include the full reimbursement to amortize loans for new buildings, the payment of indirect costs on faculty salaries, and the provision that allows 100% of faculty salaries to be supported on research grants.

Conclusion and Future Plans

The US research community cannot continue to ignore the warning signs of a system under great stress and at risk for incipient decline. We believe that the American public will continue its strong support for biomedical research and that larger budgets are possible, defensible, and desirable. However, because of structural flaws in the system, such increases can only partially ameliorate a worsening problem.

We are confident that a research system as productive and democratic as ours can correct its vulnerabilities. Some fundamental changes are required because the system cannot expand indefinitely along the current trajectory. The necessary changes are multiple and need to be made in a comprehensive fashion, not piecemeal. Such changes are likely to be difficult and are potentially damaging in the short run; hence, they need to be made with extreme care. Nevertheless, the changes need to begin immediately, because the situation we have described has grown significantly worse in just the last few years. Widespread engagement with these changes is necessary, beginning with immediate debate, strong advocacy for change, and action by individual scientists, the funding agencies, academic institutions, and other entities that control and pay for the conduct of science.

The future world of biomedical science that we envision is not smaller in human talent or financial support or less ambitious in its goals to discover and apply biological principles. Ideally, it will continue to grow. However, it would balance supply and demand in a sustainable fashion, adjust the pipeline that delivers new scientists, moderate the size of laboratories that are now difficult to fund, and restore an environment in which talented trainees and scientists can do their best work.

Our immediate goal has been to stimulate debate of the issues that concern us and the changes we propose. The task cannot be left to a self-appointed subset of senior scientists like ourselves or to the leaders of the NIH who are known to be considering many of these same problems (6). We therefore encourage academic institutions, scientific societies, funding organizations, and other interested parties to organize discussions, national and regional, with a wide range of relevant constituencies.

Some discussions of this type are already planned (20). However, mere discussion will not suffice. Critical action is needed on several fronts by many parties to reform the enterprise. No less than the future vitality of US biomedical science is at stake.

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StratEGIC

Strategies for Effecting Gender Equity and Institutional Change

Strategic Intervention Brief #8

Flexible Work Arrangements

More than half of the ADVANCE Projects in the first two rounds of grants developed policies to offer flexible work arrangements to faculty members encountering personal responsibilities or challenges with the potential to interrupt their usual work activities or time allocations. These arrangements varied in detail but typically offered adjustments in the tenure clock and in the duties required as part of active service. This Brief outlines specific policies addressing flexibility in the structure and expectations of work. Related topics are addressed in Brief #6 on tenure and promotion policies and Brief #9 on family-friendly initiatives.

Rationale

The rationale for these policies pertaining to work arrangements is that the recruitment, retention, and success of women are enhanced when formal policies accommodate both personal and professional responsibilities. While many men provide care to family members, women often handle a large part of family responsibilities; thus, policies that offer flexible work arrangements are especially important for attracting and supporting female faculty.

Institutions also benefit from offering flexible work arrangements. The existence of formal institutional policies on flexible work arrangements enhances the attractiveness of a university to potential faculty candidates. Furthermore, having made major investments to attract, hire, and provide start-up support for a faculty member, an institution benefits by making modest adjustments to work arrangements, when necessary, to ensure that the faculty member can succeed and remain with the institution. Even if informal arrangements have been made fairly regularly or easily in the past, the establishment of formal institutional policies ensures fairness for all faculty and alleviates concerns that individual chairs or deans might not consistently follow informal norms.

Purpose

Policies typically focus on providing support to faculty members in situations where personal responsibilities are unusually demanding and may require arranging or adjusting the amount of time and energy that can be allocated, for a period of time, to professional work. Such circumstances may include, although not exclusively, the addition of a child to the family through birth, adoption, or fostering duties, responsibilities for primary caregiving to a child or for elder care for a family member, or illness, injury, or disability to the faculty member or to a member of the faculty member's primary family. The types of policies that support flexible work arrangements include: stop the clock or tenure clock extensions; policies for active service/modified duties; and part-time tenure-track options.

The process of developing these policies typically has occurred either through the creation and implementation of new policies or through the revision of already existing policies. In some cases, institutions have had some existing policies, but the intervention has consisted of developing better processes for making these policies known or for their implementation. Typically the creation of policies has involved efforts by university committees and approval by governing bodies such as institutional faculty senates.

Audience

Typically policies supporting flexible work arrangements are available to both women and men faculty. Specific institutional details vary by institution. Some institutions indicate that eligibility to access certain policies requires the faculty member to engage in the relevant personal duties for a certain percentage of time. For example, some policies relating to the addition of a child to the family require the faculty member who would receive any adjustment to the tenure process or modified duties to be engaged in caregiving for more than 50% of the time. Attention to the percentage of time that a faculty member is actually engaged in caregiving is a way to offer policies to both women and men while ensuring that a non-primary caregiver does not simply accrue more time for work by tapping into the policy.

Models

Policies for flexible work arrangements typically fall into four categories:

Stop the Clock and Tenure Clock Extensions

- These policies offer provisions for stopping the tenure clock or extending it under certain conditions, including the addition of a baby by birth or adoption (some institutions include the addition of a child through foster responsibilities), health issues for the faculty member or immediate faculty members, or elder care needs.
- Some institutions' policies require automatic time added to the tenure clock in the event of the addition of a family (although the faculty member is not required to wait the additional time to be reviewed for tenure), while at other institutions faculty apply to stop or extend the tenure clock.
- Institutional policies vary in regard to how often this provision can be exercised; once or twice in the career is typical, but in some cases, the faculty member can enlist this provision as much as needed. In cases where the reason is childcare, some institutions require the faculty member to sign a statement that he or she provides more than 50 percent of the primary childcare duties.

Active Service with Modified Duties

- These policies involve adjusting the responsibilities of a faculty member for a period of time, due to birth or adoption, death of a spouse, or other family matters. Some institutions automatically arrange for a faculty member to be relieved of a course or all teaching for a semester immediately after a birth or adoption (and for faculty without teaching responsibilities to get equivalent release time).
- Arrangements in situations where a faculty member needs to provide elder care or has other personal issues are often treated on a case-by-case basis involving consultations among the faculty member and the relevant department chair, dean, and human resources department.

Part-Time Tenure Appointment Policies

- These policies cover several situations, including the employment of a tenure-track faculty member at 0.5 FTE (full-time equivalent); shifting a 1.0 FTE faculty member to 0.5 FTE for a period of time; and filling a single faculty line with two 0.5 FTE faculty members. These options are not as common as the first two types of policies, but they offer options for women and men who have significant other responsibilities, such as in the family, to engage in a full faculty life, including progressing toward tenure. Part-time tenure appointments usually involve regular responsibilities adjusted to accommodate the time frame for the position, as well as adjusted tenure timelines.

Examples

While institutions may have similar objectives (i.e., supporting sufficient flexibility in work arrangement to accommodate individuals' circumstances), the specific policies they develop usually reflect the particular cultures and circumstances within their unique organizational contexts. Here we provide several examples of the approaches various institutions have taken in developing policies to support flexible work arrangements:

- At ***Case Western Reserve University***, stop the clock arrangements are automatic for the addition of a child, and for other family matters, such as elder care responsibilities, by request (and then at the discretion of a dean). At Case, faculty members can stop the clock for family leave as many times as needed.

- At ***Kansas State University***, the Stop the Clock policy covers situations of a new child, childcare duties, and health issues for the faculty member or immediate family members. Faculty members may elect to use this provision two times in their career.
- The Handbook of Operating Procedures at the ***University of Texas at El Paso (UTEP)*** now indicates that both female and male faculty can request a delay of one year for legitimate family matters, including becoming a new parent, becoming the primary caregiver for an elderly, ill, or disabled family member, or if the faculty member is experiencing serious illness, injury, or disability. A delay of a second year may also be requested, but the tenure clock cannot be delayed more than two years. The process involves the faculty member writing a request to the department chair, the chair making a recommendation to the dean, and the dean applying to the provost, who makes the decision. Faculty members work closely with professionals in the Human Resources department to work out appropriate requests for their situations.
- ***Utah State University*** established an agreed-upon practice that men and women may use the tenure clock extension option up to two times for birth, serious health issues in the family, or serving as the primary care giver. Faculty couples can split the benefit, with one doing half-time teaching for one semester and the other the second semester. The faculty member's college pays a portion of the related costs, the provost underwrites a small portion of the financial burden, and the faculty member is paid 90% of the usual salary.
- ***The University of Montana*** modified duties policy enables any faculty member in a tenure-stream position who has caregiver responsibilities due to a birth, adoption, or care for a primary family member to be released from teaching, research, and service for one semester, with the Provost's Office providing funding for teaching replacement costs. The policy also provides the option of a one-year tenure-clock extension and the delay of annual evaluation by one year. The University of Montana also drafted policies to address part-time tenure-track options.

In developing policies and practices on flexible work-life policies, institutions tend to work on several issues:

- ***Processes and deliberations to create policies*** usually involve senior-level administrators, faculty committees, and institutional governing boards. Institutional leaders report that policies are more likely to be politically acceptable, as they move through institutional governance structures, if they address the interests and needs of both women and men.
- Creating policies is not sufficient. A ***communication plan*** should address deans and department chairs, human resources units, and faculty members themselves. Deans and especially department chairs must be aware and knowledgeable about the policies and often need support in developing and implementing effective communication strategies for making faculty aware of their options. Professionals in human resources departments also must be well aware of all policy options and prepared to help individual faculty members assess their situations and make appropriate decisions. Some institutions have developed communication strategies, including special brochures, to spread the word about the policies they have implemented to support flexible work arrangements.
- Just knowing about policies also is not enough; faculty members must feel that it is risk-free to use such policies and that they are encouraged to do so. Thus, some universities widely ***advertise their policies*** concerning flexible work arrangements and strive to normalize their use.

Evaluation

No specific evaluation has been conducted on the development of flexible work policies, but our interviews with institutional leaders, ADVANCE IT Program leaders, and faculty members indicate that such policies are important signals of institutional commitment to the success of a diverse faculty. Furthermore, a growing body of literature calls for higher education institutions to create workplaces in which faculty members can create lives that incorporate in reasonable ways both personal and professional responsibilities.

Affordances and Limitations

Institutional leaders and faculty members cite a number of benefits when institutions develop and implement policies that support flexibility in work arrangements. These benefits include:

- *Support for individual faculty members*: Arguably, institutional support in the form of policies for flexible work arrangements that help faculty members handle the challenges and circumstances that arise in life can enhance morale, institutional commitment, and energy for creativity and productivity (Gappa, Austin, & Trice, 2007). Such policies also may help individual faculty members choose to have the families they want (Mason & Goulden, 2002, 2004).
- *A more supportive campus*: Policies that support flexibility in work arrangements help change the culture of an institution. One institutional leader explained: These policy changes are "more friendly and more reflective of what the needs of our female faculty are and what the needs of our faculty are who are going through certain transitions—male or female."
- *More attention to important campus issues*: The process of developing and spreading the word about policies opens conversations and makes members of the campus community more aware of the diversity of circumstances of their colleagues, which can enhance understanding of the importance of diversity and its place in the institutional culture.
- *Symbolic value external to the institution*: When an institution has specific policies in place that support the diverse professional and personal lives of the faculty, it sends a message about its values and culture. Such symbolic messages may enhance its attractiveness to prospective faculty members.

Limitations related to polices to support flexible work arrangements include:

- *Lack of use*: Policies many not be widely used if faculty members fear that using them carries the risk of not appearing committed to one's work responsibilities and career. Explicit, widespread, and consistent messages about the policies and institutional support for their use are important steps to ensure policies become normalized aspects of employment practices.
- *Concerns about overuse of flexible work policies*: Institutional leaders have reported to us that initial concerns that the presence of policies would result in overuse by faculty members have been unfounded.
- *External perceptions*: External reviewers of tenure and promotion dossiers sometimes are unfamiliar with how to evaluate the materials of faculty members who have extended tenure clocks or participated in modified duties or part-time tenure positions. Universities need to provide explicit information and instructions in regard to the use of such policies.

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BEYOND BIAS AND BARRIERS

FULFILLING THE POTENTIAL OF WOMEN IN ACADEMIC SCIENCE AND ENGINEERING

EXECUTIVE SUMMARY

NATIONAL ACADEMY OF SCIENCES,
NATIONAL ACADEMY OF ENGINEERING, *AND*
INSTITUTE OF MEDICINE
OF THE NATIONAL ACADEMIES

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* Served from September 2005 to June 2006. This report is dedicated in her honor.

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EXECUTIVE SUMMARY

The United States economy relies on the productivity, entrepreneurship, and creativity of its people. To maintain its scientific and engineering leadership amid increasing economic and educational globalization, the United States must aggressively pursue the innovative capacity of *all* of its people—women and men. Women make up an increasing proportion of science and engineering majors at all institutions, including top programs such as those at the Massachusetts Institute of Technology where women make up 51% of its science undergraduates and 35% of its engineering undergraduates. For women to participate to their full potential across all science and engineering fields, they must see a career path that allows them to reach their full intellectual potential. Much remains to be done to achieve that goal.

Women are a small portion of the science and engineering faculty members at research universities, and they typically receive fewer resources and less support than their male colleagues. The representation of women in leadership positions in our academic institutions, scientific and professional societies, and honorary organizations is low relative to the numbers of women qualified to hold these positions. It is not lack of talent, but unintentional biases and outmoded institutional structures that are hindering the access and advancement of women. Neither our academic institutions nor our nation can afford such underuse of precious human capital in science and engineering. The time to take action is now.

CHARGE TO THE COMMITTEE

The National Academies, under the oversight of the Committee on Science, Engineering, and Public Policy, created the Committee on Maximizing the Potential of Women in Academic Science and Engineering to develop specific recommendations on how to make the fullest possible use of a large source of our nation's talent: women in academic science and engineering.

Specifically, the committee was charged

- To review and assess the research on gender issues in science and engineering, including innate differences in cognition, implicit bias, and faculty diversity.
- To examine institutional culture and the practices in academic institutions that contribute to and discourage talented individuals from realizing their full potential as scientists and engineers.
- To determine effective practices to ensure that women who receive their doctorates in science and engineering have access to a wide array of career opportunities in the academy and in other research settings.
- To determine effective practices for recruiting women scientists and engineers to faculty positions and retaining them in these positions.
- To develop findings and provide recommendations based on these data and other information to guide faculty, deans, department chairs and other university leaders; scientific and professional societies; funding organizations; and government agencies in maximizing the potential of women in science and engineering careers.

The report presents the consensus views and judgment of the committee members, who include five university presidents and chancellors, provosts and department chairs, named professors, former top government officials, leading policy analysts, and outstanding scientists and engineers—nine of whom are members of the National Academy of Sciences, National Academy of Engineering, or the Institute of Medicine, and many of whom have dedicated great thought and action to the advancement of women in science and engineering. The committee's recommendations—if implemented and coordinated across educational, professional, and government sectors—will transform our institutions, improve the working environment for women and men, and profoundly enhance our nation's talent pool.

FINDINGS

1. Women have the ability and drive to succeed in science and engineering. Studies of brain structure and function, of hormonal modulation of performance, of human cognitive development, and of human evolution have not found any significant biological differences between men and women in performing science and mathematics that can account for the lower representation of women in academic faculty and scientific leadership positions in these fields. The drive and motivation of women scientists and engineers is demonstrated by those women who persist in academic careers despite barriers that disproportionately disadvantage them.

2. Women who are interested in science and engineering careers are lost at every educational transition. With each step up the academic ladder, from high school on through full professorships, the representation of women in science and engineering drops substantially. As they move from high school to college, more women than men who have expressed an interest in science or engineering decide to major in something else; in the transition to graduate school, more women than men with science and engineering degrees opt into other fields of study; from doctorate to first position, there are proportionately fewer women than men in the applicant pool for tenure-track positions; active recruiting can overcome this deficit.

3. The problem is not simply the pipeline. In several fields, the pipeline has reached gender parity. For over 30 years, women have made up over 30% of the doctorates in social sciences and behavioral sciences and over 20% in the life sciences. Yet, at the top research institutions, only 15.4% of the full professors in the social and behavioral sciences and 14.8% in the life sciences are women—and these are the only fields in science and engineering where the proportion of women reaches into the double digits. Women from minority racial and ethnic backgrounds are virtually absent from the nation's leading science and engineering departments.

4. Women are very likely to face discrimination in every field of science and engineering. Considerable research has shown the barriers limiting the appointment, retention, and advancement of women faculty. Overall, scientists and engineers who are women or members of racial or ethnic minority groups have had to function in environments that favor—sometimes deliberately but often inadvertently—the men who have traditionally dominated science and engineering. Well-qualified and highly productive women scientists have also had to contend with continuing questioning of their own abilities in science and mathematics and their commitment to an academic career. Minority-group women are subject to dual discrimination and face even more barriers to success. As a result, throughout their careers, women have not received the opportunities and encouragement provided to men to develop their interests and abilities to the fullest; this accumulation of disadvantage becomes acute in more senior positions.

These barriers have differential impact by field and by career stage. Some fields, such as physics and engineering, have a low proportion of women bachelor's and doctorates, but hiring into faculty positions appears to match the available pool. In other fields, including chemistry and biological sciences, the proportion of women remains high through bachelor's and doctorate degrees, but hiring into faculty positions is well below the available pool.

5. A substantial body of evidence establishes that most people — men and women — hold implicit biases. Decades of cognitive psychology research reveals that most of us carry prejudices of which we are unaware but that nonetheless play a large role in our evaluations of people and their work. An impressive body of controlled experimental studies and examination of decision-making processes in real life show that, on the average, people are less likely to hire a woman than a man with identical qualifications, are less likely to ascribe credit to a woman than to a man for identical accomplishments, and, when information is scarce, will far more often give the benefit of the doubt to a man than to a woman. Although most scientists and engineers believe that they are objective and intend to be fair, research shows that they are not exempt from those tendencies.

6. Evaluation criteria contain arbitrary and subjective components that disadvantage women. Women faculty are paid less, are promoted more slowly, receive fewer honors, and hold fewer leadership positions than men. These discrepancies do not appear to be based on productivity, the significance of their work, or any other measure of performance. Progress in academic careers depends on evaluation of accomplishments by more senior scientists, a process widely believed to be objective. Yet measures of success underlying the current "meritocratic" system are often arbitrary and applied in a biased manner (usually unintentionally). Characteristics that are often selected for and are believed, on the basis of little evidence, to relate to scientific creativity—namely assertiveness and single-mindedness—are given greater weight than other characteristics such as flexibility, diplomacy, curiosity, motivation, and dedication, which may be more vital to success in science and engineering. At the same time assertiveness and single-mindedness are stereotyped as socially unacceptable traits for women.

7. Academic organizational structures and rules contribute significantly to the underuse of women in academic science and engineering. Rules that appear quite neutral may function in a way that leads to differential treatment or produces differential outcomes for men and women. Structural constraints and expectations built into academic institutions assume that faculty members have substantial spousal support. The evidence demonstrates that anyone lacking the work and family support traditionally provided by a "wife" is at a serious disadvantage in academe. However, the majority of faculty no longer have such support. About 90% of the spouses of women science and engineering faculty are employed full-time; close to half the spouses of male faculty also work full-time.

8. The consequences of *not* acting will be detrimental to the nation's competitiveness. Women and minority group members make up an increasing proportion of the labor force. They also are an increasing proportion of postsecondary students. To capture and capitalize on this talent will require revising policies adopted when the workplace was more homogeneous and creating new organizational structures that manage a diverse workforce effectively. Effective programs have three key components: commitments to take corrective action and to analyze and use data for organizational change, and a campus framework for monitoring progress.

To facilitate clear, evidence-based discussion of the issues, the committee compiled a list of commonly-held beliefs concerning women in science and engineering (see Table 1). Each is discussed and analyzed in detail in the text of the report.

Table 1: Evidence refuting commonly-held beliefs about women in science and engineering.

BELIEF	EVIDENCE	WHERE DISCUSSED
(1) Women are not as good in mathematics as men.	Female performance in high school mathematics now matches that of males.	Chapter 2
(2) The matter of "under-representation" on faculties is only a matter of time; it is a function of how many women are qualified to enter these positions.	Women's representation decreases with each step up the tenure-track and academic leadership hierarchy, even in fields that have had a large proportion of women doctorates for 30 years.	Chapter 3
(3) Women are not as competitive as men. Women don't want jobs in academe.	Similar proportions of men and women science and engineering doctorates plan to enter postdoctoral study or academic employment.	Chapter 3
(4) Behavioral research is qualitative; why pay attention to the data in this report?	The data are from multiple sources, were obtained using well-recognized techniques, and have been replicated in several settings.	Chapters 2-5
(5) Women and minorities are recipients of favoritism through affirmative-action programs.	Affirmative action is meant to broaden searches to include more women and minority-group members, but not to select candidates on the basis of race or sex, which is illegal.	Chapter 4
(6) Academe is a meritocracy.	Although scientists like to believe that they "choose the best" based on objective criteria, decisions are influenced by factors—including biases about race, sex, geographic location of a university, and age—that have nothing to do with the quality of the person or work being evaluated.	Chapter 4
(7) Changing the rules means that standards of excellence will be deleteriously affected.	Throughout a scientific career, advancement depends upon judgments of one's performance by more senior scientists and engineers. This process does not optimally select and advance the best scientists and engineers, because of implicit bias and disproportionate weighting of qualities that are stereotypically male. Reducing these sources of bias will foster excellence in science and engineering fields.	Chapter 4
(8) Women faculty are less productive than men.	The publication productivity of women science and engineering faculty has increased over the last 30 years and is now comparable to men's. The critical factor affecting publication productivity is access to institutional resources; marriage, children, and eldercare responsibilities have minimal effects.	Chapter 4
(9) Women are more interested in family than in careers.	Many women scientists and engineers persist in their pursuit of academic careers despite severe conflicts between their roles as parents and as scientists and engineers. These efforts, however, are often not recognized as representing the high level of dedication to their careers they represent.	Chapter 5
(10) Women take more time off due to childbearing, so they are a bad investment.	On the average, women take more time off during their early careers to meet their caregiving responsibilities, which fall disproportionately to women. But, over a lifelong career, a man is likely to take significantly more sick leave than a woman.	Chapter 5
(11) The system as currently configured has worked well in producing great science; why change it?	The global competitive balance has changed in ways that undermine America's traditional S&E advantages. Career impediments based on gender or racial or ethnic bias deprive the nation of talented and accomplished researchers	Chapter 6

CONCLUSIONS

The United States can no longer afford the underperformance of our academic institutions in attracting the best and brightest minds to the science and engineering enterprise. Nor can it afford to devalue the contributions of some members of that workforce through gender inequities and discrimination. It is essential that our academic institutions promote the educational and professional success of all people without regard for sex, race, or ethnicity. So that our scientists and engineers can realize their greatest potential, our academic institutions must be held accountable and provide evidence that women and men receive equitable opportunities, resources, and support. Institutional policies and practices must move from the traditional model to an inclusive model with provisions for equitable and unbiased evaluation of accomplishment, equitable allocations of support and resources, pay equity, and gender-equal family leave policies. Otherwise, a large number of the people trained in and capable of doing the very best science and engineering will not participate as they should in scientific and engineering professions.

RECOMMENDATIONS

Career impediments for women deprive the nation of an important source of talented and accomplished scientists and engineers who could contribute to our nation's competitiveness. Transforming institutional structures and procedures to eliminate gender bias is a major national task that will require strong leadership and continuous attention, evaluation, and accountability. Because those obstacles are both substantial and systemic, there are no easy fixes; however, many practices developed in the last decade by universities and funding agencies have proven effective in increasing both the participation of women on faculties and their appointment to leadership positions. In part, the challenge is to use such strategies more widely and evaluate them more broadly to ensure we are accessing the entire talent pool to find truly the best people for our faculties. We need to think creatively about opportunities for substantial and overarching reform of the academic enterprise—its structure, incentives, and accountability—to change outcomes and achieve equity

The committee's recommendations are large-scale and interdependent, requiring the interaction of university leaders and faculties, scientific and professional societies, funding agencies, federal agencies, and Congress.

Trustees, university presidents, and provosts **should provide clear leadership in changing the culture and structure of their institutions to recruit, retain, and promote women—including minority women—into faculty and leadership positions.**

- University leaders should *incorporate into campus strategic plans goals of counteracting bias against women in hiring, promotion, and treatment.* This includes working with an inter-institution monitoring organization (see below) to perform annual reviews of the composition of their student body and faculty ranks, publicizing progress toward the goals annually, and providing a detailed annual briefing to the board of trustees.
- University leaders should *take action immediately to remedy inequities in hiring, promotion, and treatment*.
- University leaders should as part of their *mandatory overall management efforts hold leadership workshops for deans, department heads, search committee chairs, and other faculty with personnel management responsibilities that include an*

integrated component on diversity and strategies to overcome bias and gender schemas and strategies for encouraging fair treatment of all people. It is crucial that these workshops are integrated into the fabric of the management of universities and departments.

- University leaders should *require evidence of a fair, broad, and aggressive search before approving appointments and hold departments accountable for the equity of their search process and outcomes* even if it means canceling a search or withholding a faculty position.

- University leaders should *develop and implement hiring, tenure, and promotion policies that take into account the flexibility that faculty need* across the life course, allowing integration of family, work, and community responsibilities. They should provide uniform policies and central funding for faculty and staff on leave and should visibly and vigorously support campus programs that help faculty with children or other caregiving responsibilities to maintain productive careers. These programs should, at a minimum, include provisions for paid parental leave for faculty, staff, postdoctoral scholars, and graduate students; facilities and subsidies for on-site and community-based child care; dissertation defense and tenure clock extensions; and family-friendly scheduling of critical meetings.

Deans and department chairs and their tenured faculty **should take responsibility for creating a productive environment and immediately implement programs and strategies shown to be successful in minimizing the effect of biases in recruiting, hiring, promotion, and tenure.**

- Faculties and their senates should initiate a *full faculty discussion of climate issues.*

- Deans, department chairs, and their tenured faculty should *develop and implement programs that educate all faculty members and students in their departments on unexamined bias and effective evaluation*; these programs should be integrated into departmental meetings and retreats, and professional development and teacher-training courses. For example, such programs can be incorporated into research ethics and laboratory management courses for graduate students, postdoctoral scholars, and research staff; and can be part of management leadership workshops for faculty, deans, and department chairs.

- Deans and department chairs and their tenured faculty should *expand their faculty recruitment efforts* to ensure that they reach adequately and proactively into the existing and ever-increasing pool of women candidates.

- Faculties and their senates should immediately *review their tenure processes and timelines* to ensure that hiring, tenure, and promotion policies take into account the flexibility that faculty need across the life course and do not sacrifice quality in the process of meeting rigid timelines.

University leaders should work with their faculties and department chairs **to** ***examine evaluation practices*** **to focus on the quality of contributions and their impact.**

Professional societies and higher education organizations **have a responsibility to play a leading role in promoting equal treatment of women and men and to demonstrate a commitment to it in their practices.**

Together, ***higher education organizations*** should *consider forming an inter-institution monitoring organization*. This body could act as an intermediary between academic institutions and federal agencies in recommending norms and measures, in collecting data, and in cross-institution tracking of compliance and accountability. Just as the opening of athletics programs to girls and women required strong and consistent inter-institutional cooperation, eliminating gender bias in faculty recruitment, retention, and promotion processes requires continuous inter-institutional cooperation, including data-gathering and analysis, and oversight and evaluation of progress.

As an initial step, the committee recommends that the American Council on Education, an umbrella organization encompassing all of higher education, convene national higher education organizations, including the Association of American Universities (AAU), the National Association of State Universities and Land Grant Colleges (NASULGC), and others to consider the creation of a cross-university monitoring body.

A primary focus of the discussion should be on defining the scope and structure of data collection. The committee recommends that data be collected at the department level by sex and race or ethnicity and include the numbers of students majoring in science and engineering disciplines; the numbers of students graduating with bachelors or master's degrees in science and engineering fields; post-graduation plans; first salary; graduate school enrollment, attrition, and completion; postdoctoral plans; numbers of postdoctoral scholars; and data on faculty recruitment, hiring, tenure, promotion, attrition, salary, and allocation of institutional resources. The committee has developed a scorecard that can be used for this purpose.

Scientific and professional societies should

- *Serve in helping to set professional and equity standards*, collect and disseminate field-wide education and workforce data, and provide professional development training for members that includes a component on bias in evaluation.
- Develop and enforce guidelines to *ensure that keynote and other invited speakers at society-sponsored events reflect the diverse membership of the society.*
- Ensure *reasonable representation of women on editorial boards and in other significant leadership positions.*
- Work to ensure that women are recognized for their contributions to the nation's scientific and engineering enterprise through *nominations for awards and leadership* positions.
- Provide *child-care and elder-care grants* or subsidies so that their members can attend work-related conferences and meetings.

Honorary societies should *review their nomination and election processes* to address the underrepresentation of women in their memberships.

Journals should *examine their entire review process*, including the mechanisms by which decisions are made to send a submission to review, and take steps to minimize gender bias, such as blinded reviews.

Federal funding agencies and foundations **should ensure that their practices—including rules and regulations—support the full participation of women and do not reinforce a culture that fundamentally discriminates against women. All research funding agencies should:**

- *Provide workshops to minimize gender bias*. Federal funding agencies and foundations should work with scientific and professional societies to host mandatory national meetings that educate members of review panels, university department chairs, and agency program officers about methods that minimize the effects of gender bias in evaluation. The meetings should be held every 2 years for each major discipline and should include data and research presentations on subtle biases and discrimination, department climate surveys, and interactive discussions or role-modeling. Program effectiveness should be evaluated on an ongoing basis.

- *Collect, store, and publish composite information* on demographics, field, award type and budget request, review score, and funding outcome for all funding applications.
- *Make it possible to use grant monies for dependent care expenses* necessary to engage in off-site or after-hours research-related activities or to attend work-related conferences and meetings.
- *Create additional funding mechanisms* to provide for interim technical or administrative support during a leave of absence related to caregiving.
- *Establish policies for extending grant support* for researchers who take a leave of absence due to caregiving responsibilities.
- *Expand support for research* on the efficacy of organizational programs designed to reduce gender bias, and for research on bias, prejudice, and stereotype threat, and the role of leadership in achieving gender equity.

Federal agencies **should lay out clear guidelines, leverage their resources, and rigorously enforce existing laws to increase the science and engineering talent developed in this country.**

Even without additional resources, federal agencies should *move immediately to enforce the federal anti-discrimination laws* at universities and other higher education institutions through regular compliance reviews and prompt and thorough investigation of discrimination complaints.[1] Federal enforcement agencies should ensure that the range of their enforcement efforts covers the full scope of activities involving science and engineering that are governed by the anti-discrimination laws. If violations are found, the full range of remedies for violation of the anti-discrimination laws should be sought.

Federal enforcement efforts should *evaluate whether universities have engaged in any of the types of discrimination* banned under the anti-discrimination laws, including: intentional discrimination, sexual harassment, retaliation, disparate impact discrimination, and failure to maintain required policies and procedures.

Federal compliance review efforts should *encompass a sufficiently broad number and range of institutions* of higher education to secure a substantial change in policies and practices nationwide. Types of institutions that should be included in compliance reviews include 2-year and 4-year institutions; institutions of undergraduate education; institutions that grant graduate degrees; state universities; private colleges; and educational enterprises, including national laboratories and independent research institutes, which may not be affiliated with universities.

Federal enforcement agencies, including the Equal Employment Opportunity Commission, the Department of Justice, the Department of Labor, the Department of Education, and individual federal granting agencies' Offices of Civil Rights should *encourage and provide technical assistance* on how to achieve diversity in university programs and employment. Possible activities include providing technical assistance to educational institutions to help them to comply with the anti-discrimination laws, creating a clearinghouse for dissemination of strategies that have been proven effective, and providing awards and recognition for model university programs.

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[1]Applicable laws include Title VI, Title VII, and Title IX of the Civil Rights Act; Executive Order 11246; the Equal Protection clause of the Constitution; the Equal Pay Act; the Pregnancy Discrimination Act; and the Family Medical Leave Act. Each of these statutes is discussed in detail in Chapter 5.

Congress should take steps necessary to encourage adequate enforcement of antidiscrimination laws, including *regular oversight hearings* to investigate the enforcement activities of the Department of Education, the Equal Employment Opportunity Commission, the Department of Labor, and the science granting agencies—including the National Institutes of Health, the National Science Foundation, the Department of Defense, the Department of Agriculture, the Department of Energy, the National Institute of Standards and Technology, and the National Aeronautics and Space Administration.

CALL TO ACTION

The fact that women are capable of contributing to the nation's scientific and engineering enterprise but are impeded in doing so because of gender and racial/ethnic bias and outmoded "rules" governing academic success is deeply troubling and embarrassing. It is also a *call to action*. Faculty, university leaders, professional and scientific societies, federal agencies and the federal government must unite to ensure that all our nation's people are welcomed and encouraged to excel in science and engineering in our research universities. Our nation's future depends on it.

FOR MORE INFORMATION

This report was developed under the aegis of the National Academies Committee on Science, Engineering, and Public Policy (COSEPUP), a joint committee of the three honorific academies—the National Academy of Science (NAS), the National Academy of Engineering (NAE), and the Institute of Medicine (IOM). Its overall charge is to address cross-cutting issues in science and technology policy that affect the health of the national research enterprise. More information on the study, including the full body of the report, is available at **http://www7.nationalacademies.org/womeninacademe/.**

NOTE

This report was reviewed in draft form by individuals chosen for their technical expertise, in accordance with procedures approved by the National Academies' Report Review Committee. For a list of those reviewers, refer to the full report.

Contracts & Grants FY 2013-14 Award Report

Focus on Federal Funding

Summary

Award funding during Q4 of 2013-14 reached a record fourth-quarter total of almost $1.7 billion, pushing the yearly total to over $5.7 billion, also a record amount. These high totals are a welcome change from last year's grim award figures, and represent an increase for the year of about 8% over 2012-13.

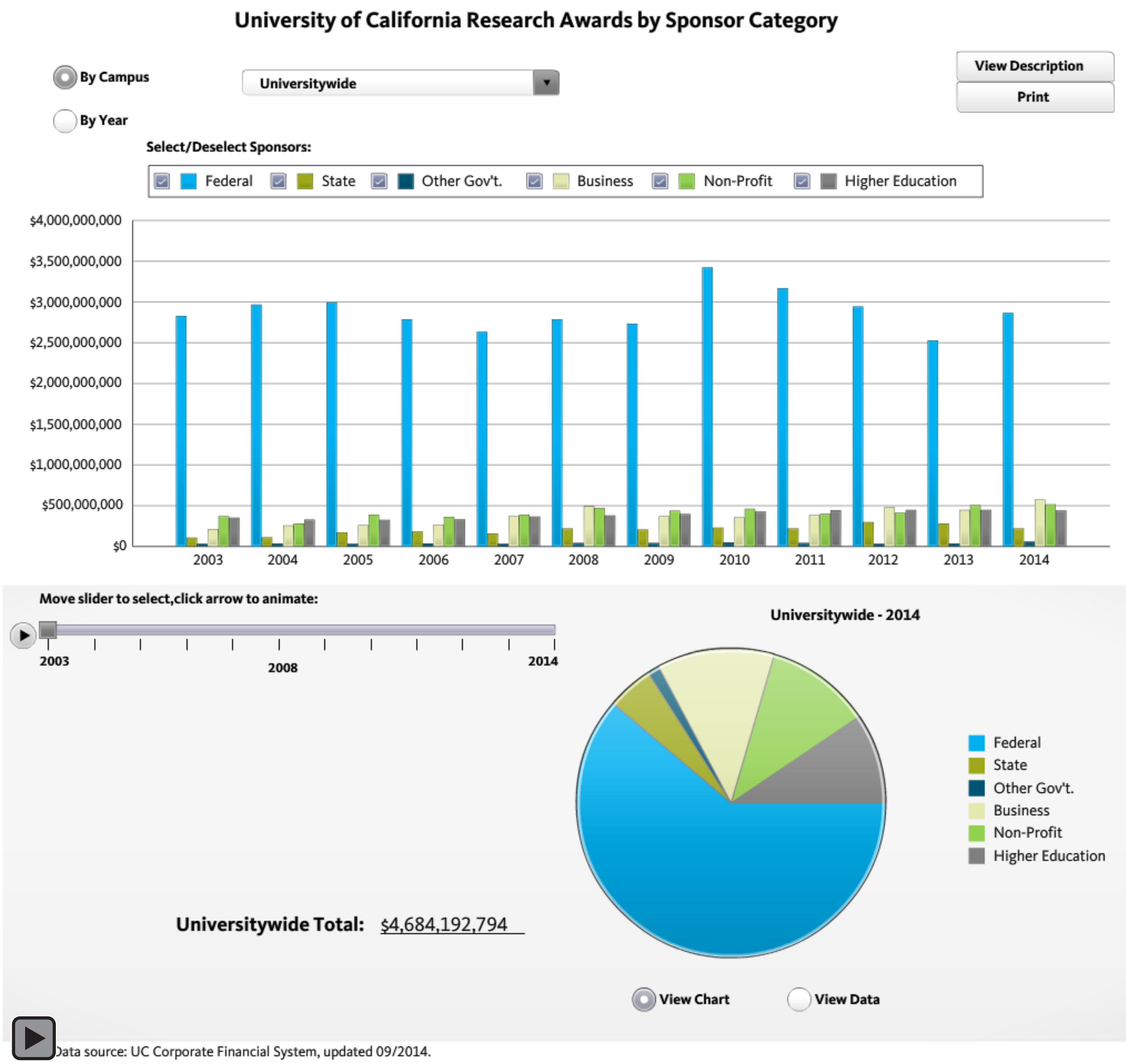
One likely reason for the record high Q4 award amount is that the US Congress finally passed a budget in January 2014, and this appears to have increased the flow of federal funds. During Q4, UC received about $1 billion in federal awards, which is about $125 million more in constant dollars than last year, when budget constraints were at their peak, and almost $60 million more than two years ago, just before the federal budget crisis. In addition, funding from state, non-profit and higher education sources also surpassed the Q4 levels of previous years, contributing significantly to the quarterly and yearly record totals.

However, given the current status of the federal budget, and UC's continued dependence on federal agency funding, the long-term prospects for the academic research enterprise at UC and nationwide remain uncertain. Federal funding is key; when the effects of inflation are taken into account, the high award totals this year signify only that UC's federal funding is regaining lost ground. Overall, award funding has finally recovered to about where it was in the pre-recessionary period of 2008-09. And, given inflation, the current yearly award total of $5.7 billion is still well below the amounts received during 2009-10 and 2010-11, when stimulus funds were available through the American Recovery and Reinvestment Act.

While state and private sources of funding are increasing in importance, federal sources still contribute at least two-thirds of UC's award funding. Two agencies—the National Institutes of Health and the National Science Foundation—are critical to the research enterprise. This Quarterly Award Report will take an in-depth look at agency funding patterns and their impact on the University's research enterprise.

I. Research Award Data Visualization

Research sponsorship generally makes up about 75-80% of the extramural support UC receives each year. The data visualization on the following page provides an interactive view of the research component of UC's extramural funding since FY 2002-03. (Note that all dollar amounts in this visualization and throughout this report are adjusted for inflation.) The visualization automatically opens when the page following this one is visible, and closes when the page is no longer on-screen. Right-clicking on the dashboard allows several other viewing options, including full-screen and floating window. (The visualization is in Flash, which may be an issue on some tablet systems.)


University of California Research Awards by Sponsor Category
By Campus
By Year
Universitywide
View Description
Print
Select/Deselect Sponsors:
Federal
State
Other Gov't.
Business
Non-Profit
Higher Education
$4,000,000,000
$3,500,000,000
$3,000,000,000
$2,500,000,000
$2,000,000,000
$1,500,000,000
$1,000,000,000
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2003
2004
2005
2006
2007
2008
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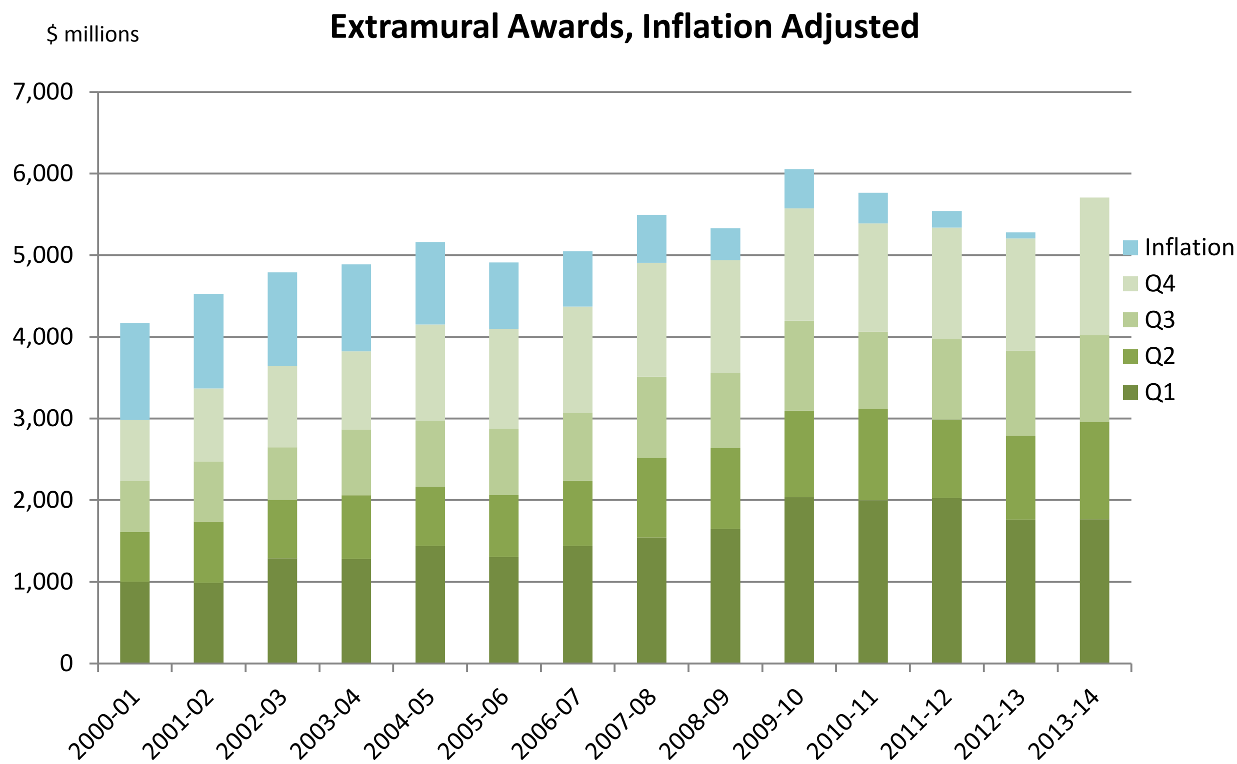
2010
2011
2012
2013
2014
Move slider to select,click arrow to animate:
2003
2008
2014
Universitywide - 2014
Universitywide Total: $4,684,192,794
View Chart
View Data
Data source: UC Corporate Financial System, updated 09/2014.

II. Quarterly Performance Metrics

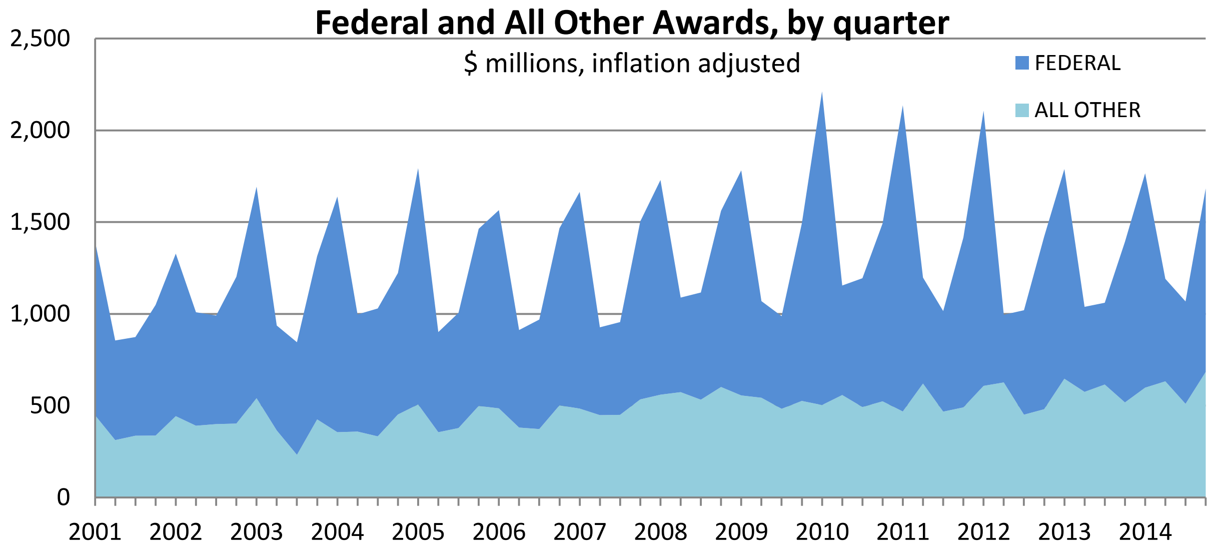
Extramural awards for Q414 totaled about $1.68 billion, almost $300 million more in constant dollars than the amounts reported during Q412 and Q413. Part of this dramatic increase is the result of higher levels of federal funding, resulting from the passage of a federal budget bill in January 2014. For the fiscal year as a whole, total funding is $5.7 billion, a record amount in absolute dollar terms, but not when inflation is taken into account.



Extramural Awards, Inflation Adjusted ($ millions)

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Q1	1,396	1,328	1,693	1,639	1,794	1,565	1,665	1,729	1,782	2,212	2,137	2,107	1,789	1,766
Q2	855	1,009	936	997	901	912	927	1,089	1,069	1,154	1,198	995	1,038	1,191
Q3	874	991	845	1,029	1,006	969	955	1,116	987	1,194	1,015	1,020	1,060	1,068
Q4	1,049	1,202	1,315	1,222	1,464	1,467	1,504	1,561	1,493	1,493	1,416	1,421	1,393	1,683
FY	***4,173***	***4,529***	***4,789***	***4,888***	***5,164***	***4,912***	***5,050***	***5,495***	***5,331***	***6,054***	***5,765***	***5,542***	***5,280***	***5,708***

Award totals for UC's first and fourth fiscal quarters are always higher than in Q2 and Q3. This is a function of the federal funding cycle, which releases the largest amounts in the final two quarters of the federal fiscal year (corresponding to UC's Q4 and Q1 of the following year). With direct federal sponsorship providing about two-thirds of all UC's awards, this produces sharp quarterly spikes in funding.



III. Award Trends by Sponsor Category

Even though awards from state and private sources during Q414 were significantly higher than during the previous year, federal awards remained by far the largest contributor to the award total. Direct federal funding to UC during Q414 was about $1 billion, a record for the quarter, but as the table below shows, this amount is only $30-40 million more than the inflation adjusted Q4 federal funding totals from 2005 forward.

($ millions)

Q4 2005	Q4 2006	Q4 2007	Q4 2008	Q4 2009	Q4 2010	Q4 2011	Q4 2012	Q4 2013	Q4 2014
965	965	970	960	967	970	925	941	875	1,000

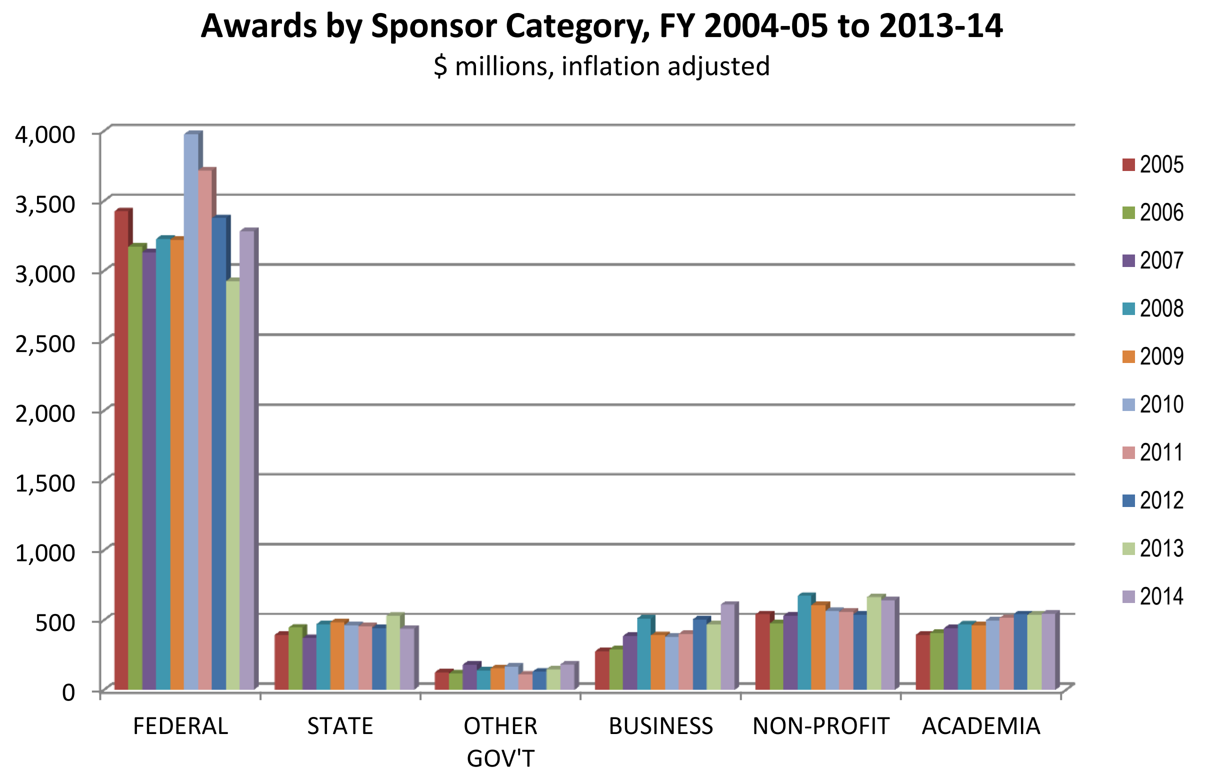
Direct federal award funding for all of FY 2014 amounted to $3.285 billion. The peak in federal funding during 2010 and 2011 was due principally to Recovery Act (ARRA) awards. For FY 2014, federal funding in constant dollars dropped to about pre-Recovery Act levels.

Awards by Sponsor Category, FY 2005-06 to 2013-14

($ millions, inflation adjusted)

SPONSOR	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*
Federal	3,173	3,135	3,229	3,224	3,977	3,719	3,378	2,927	3,285
State	447	372	472	486	465	455	445	531	439
*Other Gov't**	118	181	141	156	169	110	131	149	183
Business	290	388	512	392	380	403	506	470	612
Non-Profit	477	533	674	608	565	561	541	666	644
*Academia***	408	442	468	464	498	516	543	538	546
TOTAL	***4,912***	***5,050***	***5,495***	***5,331***	***6,054***	***5,765***	***5,542***	***5,280***	***5,708***

** Other Gov't includes Agricultural Market Order Boards.*
***Academia includes the categories of Higher Education, DOE Labs, Campuses and UCOP.*



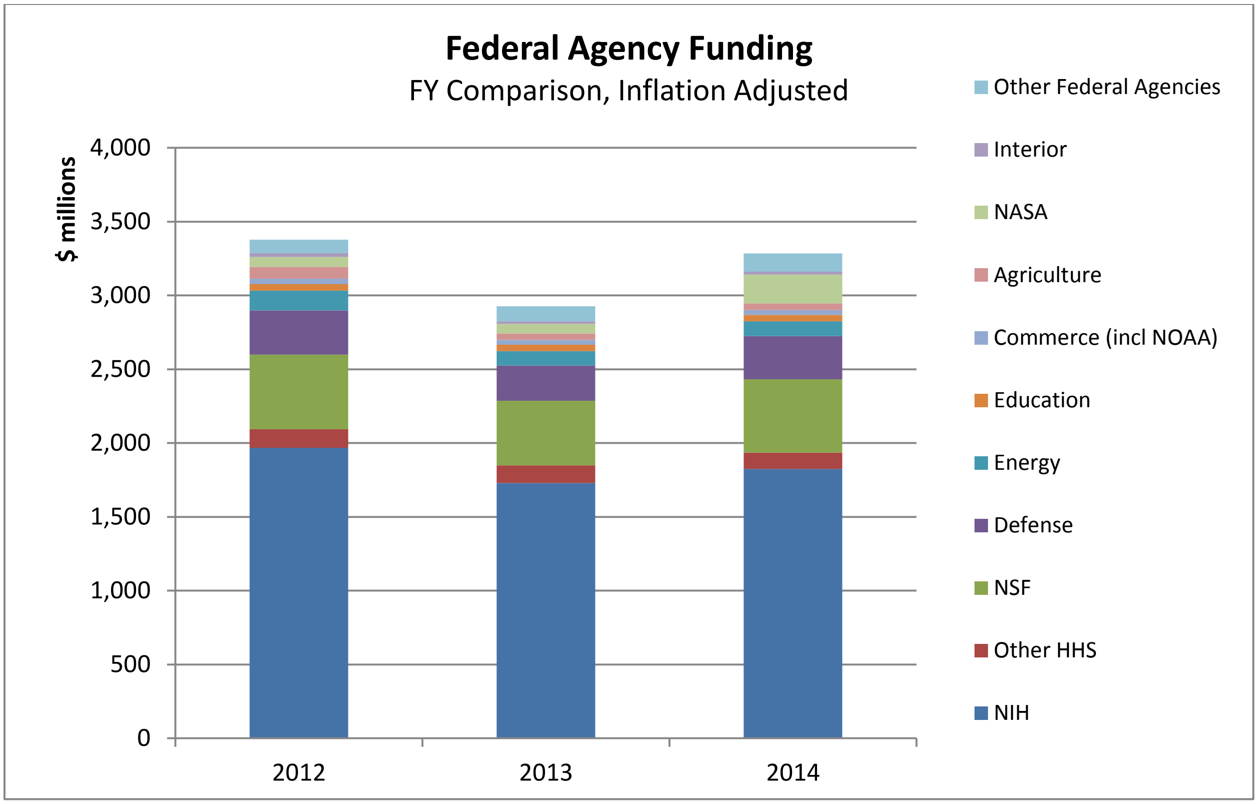
IV. Federal Agency Funding Trends

The yearly federal award total for 2013-14 is $3.285 billion. While this amount is well above last year's amount, it remains below the federal total for 2011-12, below the Recovery Act year of 2010-11, and just about on a par with the pre-recessionary federal yearly totals of 2008-09 and 2009-10. In short, only the Recovery Act has kept federal funding for UC from being absolutely flat for the past half-dozen years, once inflation is taken into account. An examination of federal funding by agency helps to pinpoint the major areas of change.

Federal Agency Funding, FY 2011-12 to 2013-14

Inflation Adjusted

AGENCY	*2012*	*2013*	*2014*	*$$ DIFFERENCE*	*% CHANGE*
NIH	1,967,077,143	1,730,275,087	1,824,273,199	93,998,112	4.8%
Other HHS	126,287,187	117,333,058	110,844,556	-6,488,502	-5.1%
NSF	505,836,124	439,353,221	497,004,369	57,651,148	11.4%
Defense	299,279,061	238,213,889	292,216,613	54,002,724	18.0%
Energy	134,592,808	98,321,114	101,103,255	2,782,141	2.1%
Education	44,338,080	42,927,944	43,387,082	459,138	1.0%
Commerce (incl. NOAA)	36,556,143	31,929,607	31,949,029	19,422	0.1%
Agriculture	79,407,137	43,219,051	46,032,606	2,813,555	3.5%
NASA	68,463,807	65,085,579	195,449,711	130,364,132	190.4%
Interior	24,289,750	19,091,760	19,371,352	279,592	1.2%
Other Federal Agencies	91,496,383	100,890,796	122,973,193	22,082,397	24.1%
TOTAL	***3,377,623,623***	***2,926,641,106***	***3,284,604,965***	***357,963,859***	***10.6%***



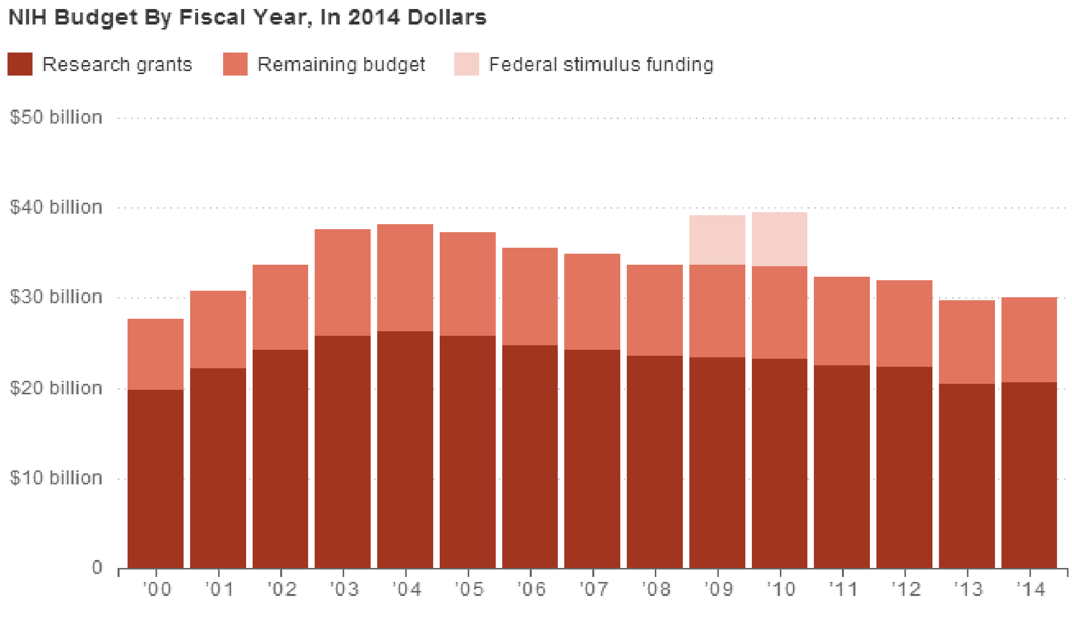
The most significant percentage increase in funding for any federal agency is an increase of 190% in awards from NASA. This is attributable to a single award of $132 million from the NASA Goddard Space Center to UC Berkeley as prime contractor in a multi-site ionospheric research project.

V. NIH and NSF Funding Analysis

Two federal agencies—the National Institutes of Health and the National Science Foundation—constitute the core of UC's federal funding. NIH generally provides nearly 60% of UC's direct federal funding (with additional amounts received as subawards), and any changes in NIH appropriations or funding practices have a significant impact on UC. The National Science Foundation is UC's second-largest source of extramural funds, supplying about 15% of the federal total, and policy changes at that agency also have a profound effect.

All federal R&D appropriations were dramatically affected by the recession and also by the Sequester of 2012-13, which slowed the flow of award funding to UC and other research universities. But the issue of federal funding, particularly for academic research and development, long predates the recession, and is directly connected to federal budget policies, which have kept agency R&D budgets essentially flat for over a decade.

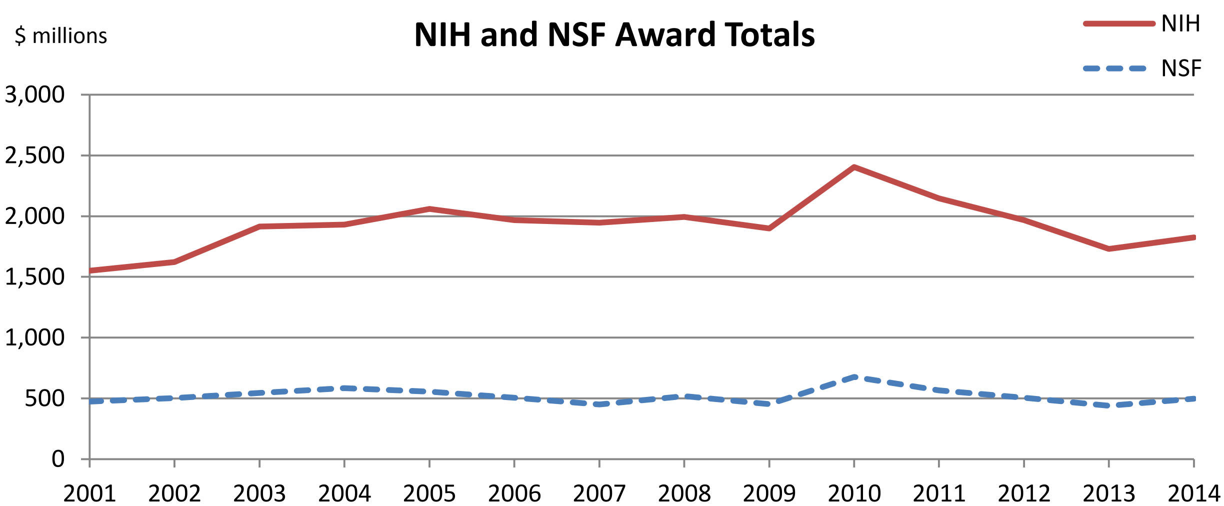
A recently released National Public Radio program series on federal funding for US science included an online article documenting the 20% decline in the NIH budget since 2004 (not counting the two-year supplement from stimulus funds). The graphic, taken from the NPR website, is based on NPR's analysis of NIH data. The appropriations situation at NSF is similar.



Notes: Figures for 2014 are preliminary. Figures for 2000-2013 have been adjusted for inflation using the Biomedical Research and Development Price Index. Federal stimulus funds in 2009-2010 came from the American Recovery and Reinvestment Act of 2009.

Source: NPR analysis of NIH data; NIH (PDF: 2000-2013, 2014); recovery.nih.gov
Credit: Robert Benincasa, Richard Harris and Alyson Hurt/NPR

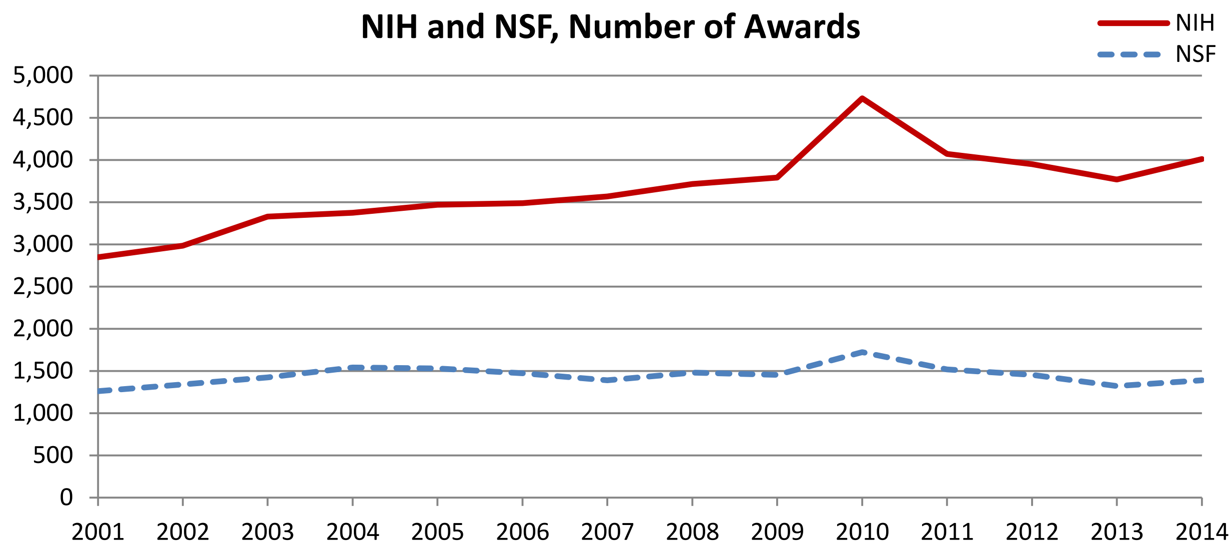
Not surprisingly, UC's award funding from NIH and NSF closely parallels the trend in NIH research grants, including the two-year spike due to stimulus funds, and dropping about 20% from the '04 –'05 peak. (Note that UC's fiscal years begin one quarter earlier than federal fiscal years, and this accounts for the offset in the stimulus funding spike.)



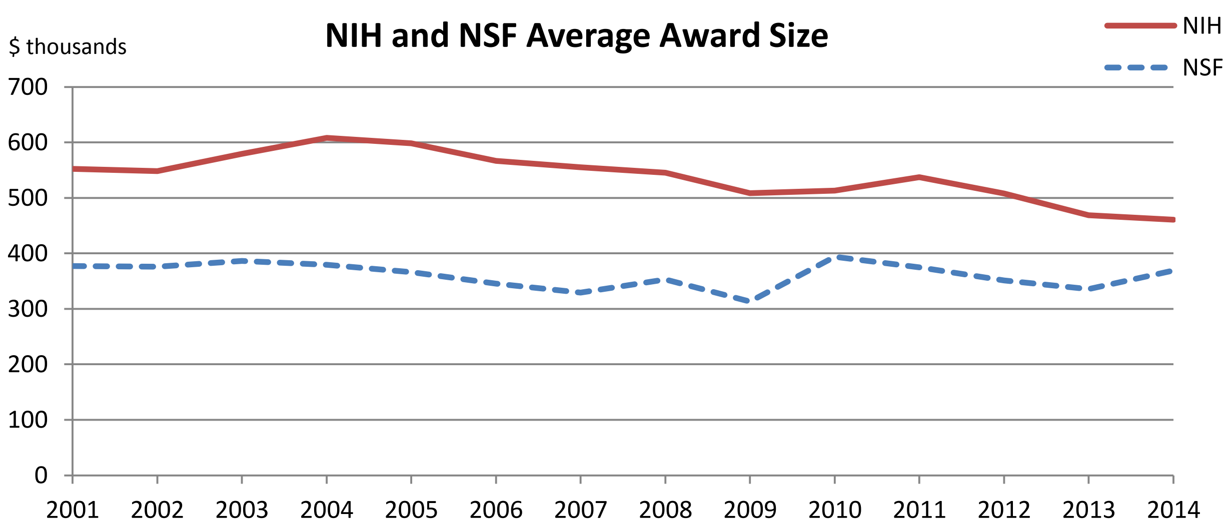
($ millions)

FY	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*
NIH	1,551	1,622	1,914	1,932	2,060	1,967	1,946	1,993	1,899	2,406	2,146	1,967	1,730	1,824
NSF	473	503	546	583	555	506	449	517	452	676	566	506	439	497

The award totals from NIH and NSF do not tell the entire story of UC's federal funding. At the same time as the award total has been shrinking, the number of awards received by UC has increased—though more so at NIH than NSF. This means that the average award size has been growing smaller, particularly at NIH, and this is consistent with the agency's recent policy of granting awards with shorter terms and smaller budgets.



FY	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*
NIH	2,848	2,984	3,329	3,375	3,468	3,489	3,568	3,714	3,789	4,730	4,070	3,949	3,768	4,010
NSF	1,262	1,341	1,425	1,543	1,529	1,475	1,391	1,479	1,453	1,722	1,520	1,454	1,321	1,389



FY	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*
NIH	552	548	579	608	598	567	555	545	509	513	537	508	469	461
NSF	377	376	386	380	366	346	329	353	313	394	375	351	336	369

Award counts and totals include both regular and Recovery Act awards of $5K and above. Continuations and renewals may be counted as separate awards even if they are reported in the same fiscal year. All project types are included, not limited to research.

As a result, UC investigators must submit proposals more frequently if they are to sustain funding for their projects and laboratories. Proposals from campuses show a dramatic increase in submissions to NIH over the past four years (the post-Recovery Act period), and a smaller increase in NSF proposals, which in turn means a larger investment of personnel resources for a financial return that is declining or at best, flat.

	NIH Proposals				***NSF Proposals***			
Fiscal Year	FY 2011	FY 2012	FY 2013	FY 2014	FY 2011	FY 2012	FY 2013	FY 2014
Number of Proposals	4,888	5,201	5,784	6,234	2,696	2,845	3,041	3,089

These proposal and award numbers suggest that it is becoming increasingly difficult and costly to secure research funds from NIH and NSF, and likely other federal agencies as well. Yet, there is no indication so far that UC has become any less competitive in securing federal funds, compared to other research institutions. Agency policies regarding issuance of smaller and fewer awards are being applied across the board, contributing to the drop in federal funding. UC's share may be remaining the same, but it is the pie that is shrinking.

V. Award Trends by Project Type

Research awards during Q414 amounted to $1.39 billion, including $78 million in clinical trial sponsorship. Training, service and other awards came to about $298 million. For the year, research awards came to nearly $4.7 billion, including $291 million in clinical trial awards.

Q4 Award Amounts by Project Type, ($ millions)

PROJECT TYPE	*Q407*	*Q408*	*Q409*	*Q410*	*Q411*	*Q412*	*Q413*	*Q414*
Research	1,189	1,196	1,137	1,163	1,097	1,131	1,100	1,307
Clinical Trials	47	48	39	53	60	67	65	78
Training	76	95	111	97	98	111	73	89
Service	137	118	108	116	86	68	92	121
Other	56	104	98	64	75	44	62	88
TOTAL	***1,504***	***1,561***	***1,493***	***1,493***	***1,416***	***1,421***	***1,393***	***1,683***

Fiscal Year Award Amounts by Project Type, ($ millions)

PROJECT TYPE	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*
Research	3,788	4,180	4,036	4,760	4,488	4,393	3,948	4,393
Clinical Trials	170	222	163	203	184	235	314	291
Training	306	370	342	361	363	329	282	292
Service	470	345	422	360	360	312	391	412
Other	317	378	367	370	370	273	345	319
TOTAL	***5,050***	***5,495***	***5,331***	***6,054***	***5,765***	***5,542***	***5,280***	***5,708***

VI. Significant Awards

During FY 2013-14, UC received about 25,400 contracts and grants from over 3,600 different sponsors (in addition to several thousand Material Transfer Agreements). Listed below are the largest or most significant awards reported this fiscal year by campuses, Agriculture & Natural Resources, Lawrence Berkeley National Lab and the Office of the President.

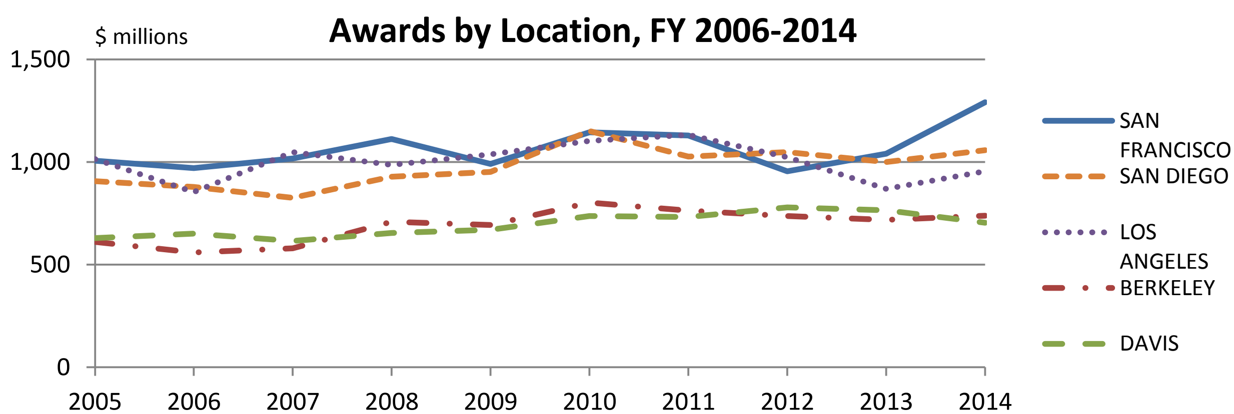
LOCATION	SPONSOR CATEGORY	SPONSOR	PROJECT TITLE
Agriculture & Natural Resources	Federal	US Geological Survey	Identification of Seasonal and Decadal Drought Through Monitoring and Modeling
Berkeley	Federal	NASA Goddard Space Flight Center	The Ionospheric Connection Explorer (ICON)
Davis	State	California Department of Food and Agriculture	South Valley Animal Health Laboratory, Tulare
Irvine	Federal	Department of Education, Assistant Secretary for Educational Research & Improvement	The Pathway to Academic Success: A Cognitive Strategies Approach to Text-Based Analytical Writing to Improve Academic Outcomes
Lawrence Berkeley National Lab	Federal	US Army Medical Research and Materiel Command.	Understanding and Modeling Aggressive ER+ Luminal Adenocarcinoma
Los Angeles	Federal.	National Institutes of Mental Health National Center for Advancing Translational Science	UCLA Clinical and Translational Science Institute
Merced	Federal	National Science Foundation	Southern Sierra Critical Zone Observatory
Office of the President	Non-Profit	Gordon and Betty Moore Foundation	Construction of the 30-Meter Telescope at Mauna Kea
Riverside	Non-Profit	First 5 Riverside	Comprehensive Approach to Raising Educational Standards—CARES Plus Program
San Diego	Business	Eli Lilly	Anti-Amyloid Treatment in Asymptomatic Alzheimer's Disease
San Francisco	Business	Daiichi Sankyo Company	Therapeutics and Molecular Diagnostics for Neurodegenerative Diseases
Santa Barbara	Federal	National Science Foundation	Center of Excellence for Materials Research and Innovation at UCSB
Santa Cruz	State	California Institute for Regenerative Medicine	Center of Excellence for Stem Cell Genomics

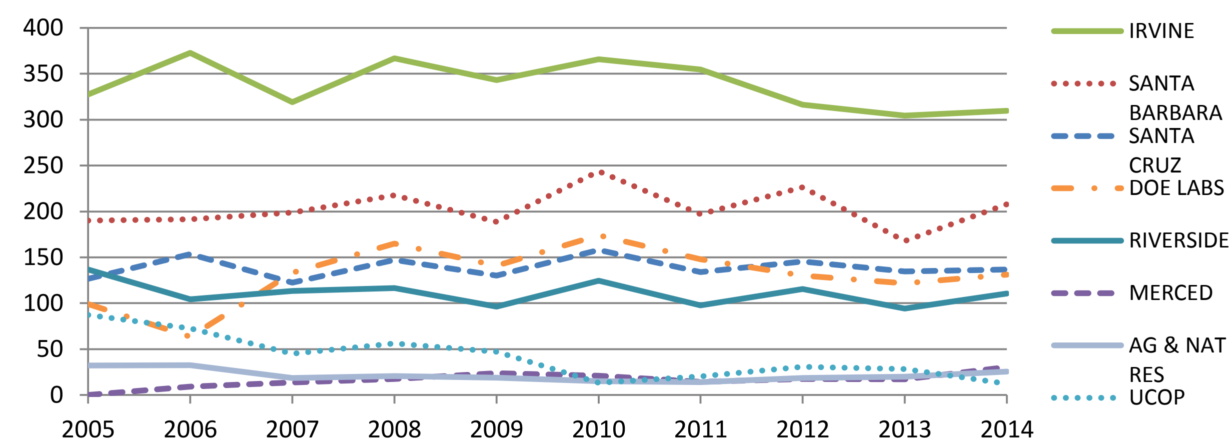
VII. Award Trends by Recipient Location

Award totals for FY 2013-14 were about 8% above last year. This increase was unevenly divided, with Merced, ANR, UCSF and UCSB showing the largest percentage increases.

FY Awards by Location

UC LOCATION	FY 2012	FY 2013	FY 2014	Change
BERKELEY	736,252,905	718,528,436	737,492,808	2.6%
SAN FRANCISCO	954,425,756	1,040,029,273	1,290,334,598	24.1%
DAVIS	778,751,181	764,424,498	704,342,286	-7.9%
LOS ANGELES	1,023,543,820	869,666,099	954,331,053	9.7%
RIVERSIDE	115,659,543	94,113,509	110,579,790	17.5%
SAN DIEGO	1,048,532,368	999,113,495	1,057,066,247	5.8%
SANTA CRUZ	145,645,158	134,539,513	136,742,321	1.6%
SANTA BARBARA	226,213,628	167,922,979	207,820,520	23.8%
IRVINE	316,307,103	304,336,382	309,763,250	1.8%
MERCED	17,510,322	17,194,931	30,450,848	77.1%
UCOP	30,705,983	28,454,245	12,217,570	-57.1%
LBNL	130,216,884	121,754,378	131,070,635	7.7%
AG & NAT RES	18,558,922	20,056,379	25,607,370	27.7%
TOTAL	**5,542,323,573**	**5,280,134,117**	**5,707,819,296**	**8.1%**



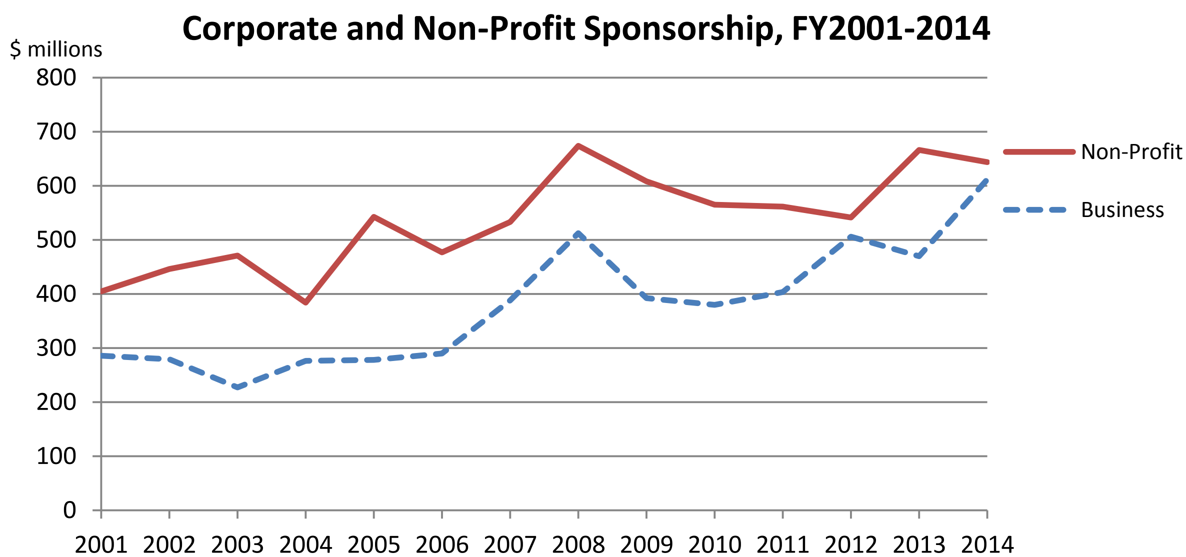


VIII. Private Funding Increases

In contrast to federal agency funding, which has remained essentially flat for the last decade, private sources of funding have been steadily increasing in both dollar amount and relative importance. In 2013-14, industry and the non-profit sector provided about $1.25 billion, about $120 million more than the prior year and about $200 million more than in FY 2011-12. That increase, together with relatively flat federal funding, has pushed the annual direct federal contribution to below 60%. However, an additional $520 million in federal funds, or another 9%, came to UC indirectly during FY 2013-14 as sub-awards (flow-through funds) from non-federal contractors. The dependence on federal funds, though less than it has been in the past, remains extremely high.

FY Extramural Funding Sources, % of Total

	2006	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*
FEDERAL	64.6%	62.1%	58.7%	60.5%	65.7%	64.5%	60.9%	55.3%	57.5%
STATE	9.1%	7.4%	8.6%	9.1%	7.7%	7.9%	8.0%	10.1%	7.7%
OTHER GOV'T	2.4%	3.6%	2.6%	2.9%	2.8%	1.9%	2.4%	2.8%	3.2%
BUSINESS	5.9%	7.7%	9.3%	7.4%	6.3%	7.0%	9.1%	8.9%	10.7%
NON-PROFIT	9.7%	10.6%	12.3%	11.4%	9.3%	9.7%	9.8%	12.6%	11.3%
ACADEMIA	8.3%	8.8%	8.5%	8.7%	8.2%	9.0%	9.9%	10.3%	9.6%

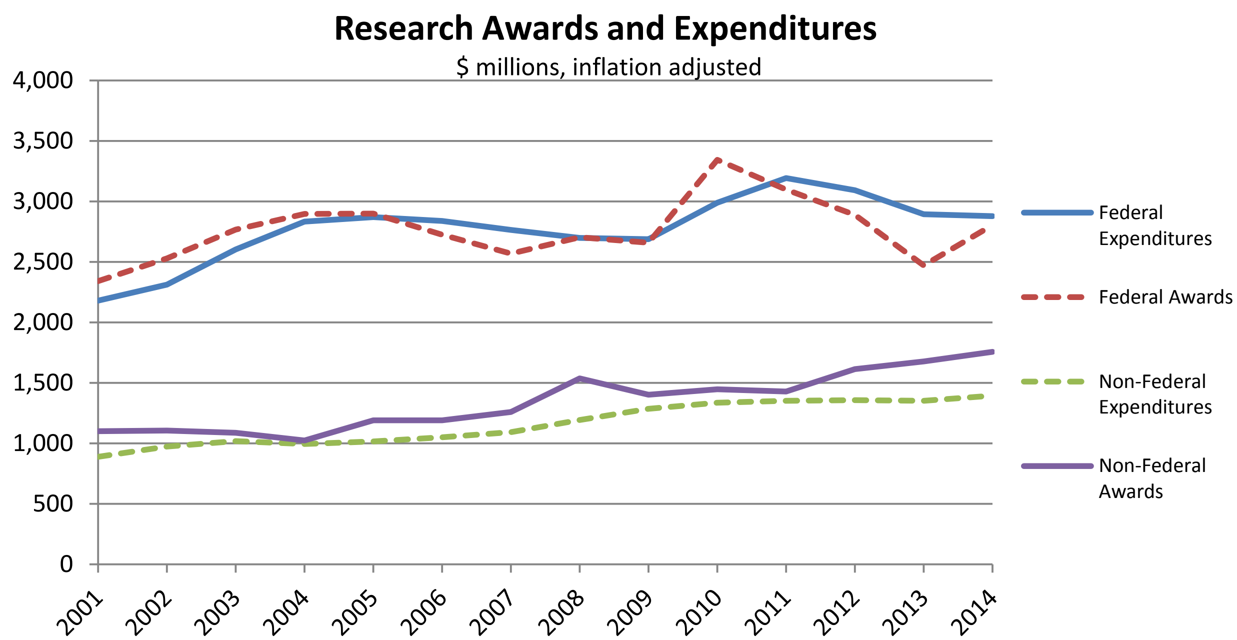


IX. Implications for the Research Community

Even though the federal budget bill that passed through Congress earlier this year restored some of the R&D funds for NIH and other agencies, appropriations are still well below where they were prior to the Budget Control Act and the Sequester. For at least the next two years, agency funding is frozen at current levels. For NIH, which is UC's main source of research funding, the current appropriation level, after adjusting for inflation, is the lowest it has been in over a decade.

As long as federal agency funding remains flat or in decline, and the subject of deep political controversy, UC's extramural funding prospects will remain under a cloud of uncertainty. The state and private sources that, for the moment, are taking up some of the funding slack are not as reliable as the proposal-driven federal award system. The uncertainty of these non-federal sources, and the generally shorter duration of non-federal awards, makes it more difficult for UC to maintain continuity in its research programs and a stable research enterprise.

What we can expect, however, is a research enterprise that is somewhat smaller than it has been over the past few years, now that stimulus funds have been completely spent.



Recovery Act awards provided only a temporary increase in research activity and employment that private sources of funding have not been entirely able to sustain. Among those who have been particularly affected by the decline in research activity are Graduate Student Researchers (GSRs). Since 2009-10, when Recovery Act funds first became available for research, the number of GSRs employed by UC has declined 8.2%, from 14,725 to about 13,500, and the amount paid to GSRs has dropped by about 12.6% in constant dollars.

The decline in graduate student research participation is only one of many structural consequences for UC of the boom and bust cycle of federal funding for research. What the GSR employment data bring into clear focus is the critical connection between UC's research enterprise and its instructional mission, and how disruptions in one inevitably cascade into the other.

Charles Drucker
Institutional Research and Academic Planning
October, 2014

Sustainability of the Academic Enterprise in the United States

My interest in entrepreneurship in nanotechnology inspired my recent participation in the National Science Foundation (NSF) iCorp program.[1] What are the needs of potential customers, the amount of money they are willing to spend, and the costs of production at high-tech enterprises? However, I soon started thinking about how much ingenuity and entrepreneurship we need to apply in running the everyday operations of a university laboratory—the academic enterprises that give birth to new technologies. This subject of the academic enterprise itself and its costs—monetary and personal—appear to me more urgent.

The economics of an academic enterprise are pretty simple. A professor applies for grants to federal agencies, industry, and foundations. If those agencies like the professor and his research group's ideas and products, and trust in their ability to deliver, they give the group the money to implement them. The support goes to pay for the workforce (students, postdocs, staff, *etc.*), facilities, and raw materials.

Looking at the research process from this perspective gave me pause. It seems that the economic foundation of our research enterprise is in trouble. Its current business model based on this description is not sustainable with its current trajectory. The academic enterprise in the United States is threatened by the inability of our customers (*i.e.*, our funding agencies) to pay for our products. I do not want to give a macroeconomic assessment that can be found in official reports but rather to share some observations "from the trenches". A systematic review of these difficulties is also beyond my capabilities because, in fact, I have to complete my own NSF proposal as soon as possible!

> The economic foundation of our research enterprise is in trouble.

First, the cost for the research workforce is constantly increasing, while the amount of money available to pay for it is persistently constant or decreasing. In fact, one typical single-investigator grant from the NSF or another federal agency cannot fund the research work of even a single Ph.D. student at my university when taking into account its full costs: stipend, tuition, benefits, and research expenses (facilities, chemicals, publications, *etc.*). Second, when I participate in NSF and National Institutes of Health (NIH) panels, of five to eight deserving proposals (from a total of 20 or 30) that propose exciting ideas, have PIs with top-notch past performance, and garner support of the panels, typically only one to three of them will eventually be funded, often with a much reduced budget. In the language of simple economics, the majority of professors and their students are not getting a return for the time they spent preparing their ideas and proposals. The resources used for the acquisition of preliminary results need to be covered from other sources, as well. Third, there are few opportunities to replace aging analytical and other routine instrumentation in established laboratories. Exceptions include NIH proposals with modular budgets, rare center grants with designated shared facilities, and equipment-focused programs with submissions from (even large) universities limited. Adding a routine $100,000 fluorescence spectrometer breaks the bank of any proposals to NSF, the Department of Defense, or industry; inclusion of instrumentation is often discouraged. Fourth, a dedicated and sympathetic program manager from one of these agencies responsible for basic research informed me that the budget for this agency was reduced by 27%. Under the program, managers have trouble fulfilling their obligations even to previously made grants. Fifth, the large instrumentation base in shared facilities essential for scientific discoveries in countries such as China, Singapore, and South Korea is often significantly better than in comparable universities in the United States. These are the countries that plan to be technological leaders and are making the investments necessary to realize these goals.

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I suspect that our readers can find more signs of trouble without encouragement. Some of the signs relate to intangible aspects of the academic enterprise. I would not underestimate them in assessing academia's sustainability because it is so strongly dependent on human factors. Although there is a good measure of prestige and freedom of direction associated with an academic position in the United States and ever increasing start-up funds provided by American colleges and universities to their young faculty, the attractiveness of academic jobs in the United States seems to be decreasing.[2] Many of our own group alumni choose to start their academic careers overseas, whereas they previously would have been more likely to stay in the United States. I was initially surprised, but then the logic became clear. The probability of getting a project funded is low, let us say 15%. Many would argue that it is lower, but let us consider the best case scenario for a young faculty with many exciting projects in mind that can electrify the review panels. By burning the midnight oil, one can write perhaps one fundable proposal per month (including revisions). This excruciating effort gives the principal investigator (PI) a reasonable chance to have funding for approximately one student. Repeating this cycle for a period of three years will give the PI three or so students and hopefully some summer salary. Will that be enough to get tenure? Will there be enough time left to write papers and to fight through their rejections? What is more important, a strong family or a strong career? These are painful questions that do not bode well for raising the hopes of talented young American and immigrant scientists. This situation does not sustain academic excellence in this country.

Another observation from the trenches is that the same doubts affect senior faculty. They are exemplified by the recent departures of several high-profile scientists to other countries. These scientists are dedicated, die-in-the-office, award-winning academicians who were nothing but successful in their academic enterprises. Since the second half of the 20th century, the United States has been the special destination for global academic talent, but there are strong indications that this trend is now being reversed. Our customers care about it as much as we do. We are in this situation together and are interested in the same outcome. Fixing the misguided strangulation of our domestic research enterprise will require both entrepreneurship and activism. Doing so will advance domestic *and* global science, technology, and medicine, as well as our economies.

Fixing the misguided strangulation of our domestic research enterprise will require both entrepreneurship and activism.

Disclosure: Views expressed in this editorial are those of the author and not necessarily the views of the ACS.

Nicholas A. Kotov
Associate Editor

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Inequality and cumulative advantage in science careers: a case study of high-impact journals

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Abstract

Analyzing a large data set of publications drawn from the most competitive journals in the natural and social sciences we show that research careers exhibit the broad distributions of individual achievement characteristic of systems in which cumulative advantage plays a key role. While most researchers are personally aware of the competition implicit in the publication process, little is known about the levels of inequality at the level of individual researchers. Here we analyzed both productivity and impact measures for a large set of researchers publishing in high-impact journals, accounting for censoring biases in the publication data by using distinct researcher cohorts defined over non-overlapping time periods. For each researcher cohort we calculated Gini inequality coefficients, with average Gini values around 0.48 for total publications and 0.73 for total citations. For perspective, these observed values are well in excess of the inequality levels observed for personal income in developing countries. Investigating possible sources of this inequality, we identify two potential mechanisms that act at the level of the individual that may play defining roles in the emergence of the broad productivity and impact distributions found in science. First, we show that the average time interval between a researcher's successive publications in top journals decreases with each subsequent publication. Second, after controlling for the time dependent features of citation distributions, we compare the citation impact of subsequent publications within a researcher's publication record. We find that as researchers continue to publish in top journals, there is more likely to be a decreasing trend in the relative citation impact with each subsequent publication. This pattern highlights the difficulty of repeatedly producing research findings in the highest citation-impact echelon, as well as the role played by finite career and knowledge life-cycles, and the intriguing possibility that confirmation bias plays a role in the evaluation of scientific careers.

Keywords: science of science; computational sociology; Matthew effect; career growth; citation analysis; reputation; success premium

1 Introduction

The business of science is constantly evolving, on multiple levels and time scales, and this evolution has a profound impact on the institutions and individuals engaged in the production of scientific research. Competition plays a central role in pushing science forward, from the winner-takes-all race for the priority of discovery, to the awarding of research funds, and the challenge in obtaining a tenure-track faculty position [1–3]. However, high levels of competition and inequality can be detrimental to the overall functioning of the science system [4–8], for example by affecting scientists' decision processes and sentiments of ethical responsibility [3, 9–14], and by altering the entry rate, the exit rate, and the overall appeal of careers in science [2, 15–18].

Ideally, academia should provide a science career path that is sustainable yet competitive and efficient [1, 18–21]. However, the improvement of the current career system in science requires a better understanding of how various complex social ingredients - reputation, cooperation, competition, risk-taking, and creativity - fit together. To begin with, two hallmarks of complex systems stand out as fundamental to improving our understanding of the complex science system:

(i) correlated behavior between individuals, due to the competition for finite resources, the increasing role of collaborative teams in science [3, 22], and ideation process arising from the combination of novel versus grounded ideas [23],
(ii) systemic memory, whereby cumulative advantage and reputation are known to play a strong role when integrated across the career [18, 24–28].

Here we investigate the high levels of inequality across researcher careers, and then quantify the role of cumulative advantage by analyzing longitudinal patterns of productivity and impact. Our focal unit throughout the analysis is the scientific career, even though we use publication and citation counts as the central quantitative measure. Our data comprises 412,498 publications drawn from 23 individual high-impact journals indexed by Thompson Reuters Web of Knowledge (TRWOK). From these data we extracted the publication profile of 258,626 individual scientists, where each trajectory is defined *within a set of journals*.

By analyzing researcher profiles within prestigious journals, we gather insights into the ascent of top scientists and the operational value of these highly-selective 'competitive arenas'. We focus most of the analysis on a case study of two journal sets in parallel, one representing the natural sciences and the other the economic sciences, each comprised of the highest impact journals in each domain. For the natural sciences we aggregated *Nature*, *the Proceedings of the National Academy of Science (PNAS)*, and *Science*. For the economic sciences we aggregated 14 highly cited journals (e.g. *American Economic Review*, *Quarterly Journal of Economics*, etc.), selected based on a page-ranking algorithm applied to journal citation data performed by *SCImago Journal & Country Rank* (http://www.scimagojr.com/index.php). Table 1 lists the journals comprising each journal set *j*.

In what follows, we explore at length and depth the statistical patterns that reflect the complex social processes underlying cumulative advantage in science. Our data are lim-

Table 1 Summary of journal set datasets

Journal set *j*	Years	Articles	Authors, R^j
Cell	1974-2012	12,349	20,521 (1,006)
Economics (top 14 journals)	1899-2012	44,571	11,882 (1,791)
Management Sci. (top 3 journals)	1954-2012	18,836	6,801 (479)
Nat./PNAS/Sci.	1958-2012	219,656	123,165 (10,317)
New England J. Med. (NEJM)	1958-2012	18,347	34,828 (916)
Phys. Rev. Lett. (PRL)	1958-2012	98,739	61,429 (13,085)

R^j is the number of 'sufficiently rare' surnames (see the Data & Methods section) we were able to identify in each journal set j over the denoted period. The R^j value in parentheses denotes the number of researcher profiles with $L_i \geq 5$, $N_p \geq 5$, and $y^j_{i,0} \geq 1960$ (Econ.) and $y^j_{i,0} \geq 1970$ (other).

ited in the sense that we are not able to pinpoint the specific covariates associated with cumulative advantage at the individual level (e.g. the emergence of individual reputation [26, 28], access to financial and human capital resources [29], refinement of talent and efficiency, collaboration spillovers [18, 27, 30], etc.). For an in-depth study using a control versus treated regression analysis approach, which astutely pinpoints specific covariates underlying the Matthew effect in science, see [28]. Here we take an alternative data-science approach, using longitudinal trends at the individual career level to provide novel insight into the emergence of cumulative advantage in the context of large number of scientists competing for limited publication space in prestigious journals.

To this end, we begin in Section 2.1 with a visualization of the historical publication patterns of highly-cited scientists in the natural and economic sciences. Following that, we present our analysis of the aggregate citation distribution of individual researchers and observe remarkable statistical regularities in the broad distribution of total citations within each publication 'arena'. We then compare these results with the distribution of longevity and productivity, finding that the skewed productivity distributions persist even among the scientists with the greatest longevity in each journal set. We also calculate the Gini inequality indices for both publications and cumulative citations. These initial descriptive analyses beg the question: How might these skewed distributions, representing relatively high levels of inequality in science, emerge at the micro level of individual careers?

To address this basic question, we used the longitudinal data for individual researchers in two complementary analyses to provide evidence for the manifestation of cumulative advantage. First, in Section 2.2 we analyze the waiting times between successive publications in these highly competitive journals. By analyzing the research profiles of prolific scientists within elite journals, our quantitative method shows how cumulative advantage manifests as an increasing publication rate. In Section 2.3 we present our second main result, showing that the relative citation impact of these researchers tends, on average, to decrease with each subsequent publication.

2 Results

2.1 General evidence of cumulative advantage in scientific careers

Given the complex institutional, economic, and behavioral factors at play in the academic career system it is no surprise that careers in science demonstrate two of the hallmark features of complex systems: strong correlations and long-term memory. For evidence of strong correlations one needs not look further than the collaboration and citation networks, which together serve as a backbone for the flow of reputation [26, 27]. Long-term systemic memory plays a role in the emergence of researcher reputation, and likely plays a strong role in social stratification [31–33]. Consequently, non-linear feedback can amplify small, early career, differences into large differences in successful outcomes over the course of scientific careers, a divergence which follows from integrating the 'Matthew effect' across time [24, 25, 34].

In this section we provide a descriptive analysis of research careers defined within two distinct sets of high-impact journals. The first set of economic researcher profiles are drawn from 14 highly-cited journals in political, financial, theoretical, and empirical economics. The second set of natural science researchers are drawn from the multidisciplinary journals Nature, PNAS, and Science. While we also analyzed other high-impact journal sets in the management science, cell biology, medicine, and physics domains, in the interest of doing a side-by-side comparison, we focus mainly on the economics and multidisciplinary natural science journals sets. Within each journal set dataset we performed a name disambiguation estimation by analyzing only the research profiles of the sufficiently 'rare' surname + given-name combinations that we aggregated from the author lists. This disambiguation strategy was recently benchmarked on datasets of similar size to ours, demonstrating a remarkably high precision given its basic approach [35]. We defer our in-depth description of our disambiguation approach to the Appendix.

We start with two motivational questions to help guide our intuition on the path researchers take to success: Are the citation trajectories of top-cited scientists similar? Are the growth patterns smooth or marked by singular events? To answer these questions we first calculate the cumulative citation impact achieved by a given researcher, i, via his or her publications in a given journal set, j. It is important to note that citation counts are time and discipline dependent, and so we standardized our citation measures by normalizing each publication's net citation count by the average total citation count of all publications published in the same year y in j. This method effectively suppresses the time and discipline dependence [36, 37].

Hence, the normalized citations of a paper, p, published in a journal belonging to the journal set j in year y is given by

$$\tilde{c}^{j}_{i,p}(y) = c^{j}_{i,p,Y}(y)/\langle c^{j}_{Y}(y)\rangle, \tag{1}$$

where $c^{j}_{i,p,Y}(y)$ is the total number of citations in census year Y to publication p published in j in year y, and $\langle c^{j}_{Y}(y)\rangle$ is the average citations calculated over all publications in j from the same year. Y is the year when the citation data was collected from TRWOK (corresponding to 2009 for Nat./PNAS/Sci. and 2012 for the economics journals, see the Appendix for further explanation). It is worth mentioning that, despite the fact that Nature, PNAS, and Science are multidisciplinary journals, for the sake of our analysis, controlling for the base citation rate is the most important reason for the normalization in Eq. (1). Hence, in this regard, PNAS, Science and Nature are comparable since they each have roughly the same order of magnitude in their base citations rates (i.e. the total number of times their articles are cited per year).

Using the normalized citation count $\tilde{c}$, we define a scientist's net citation count $\tilde{C}^{j}_{i}(y)$ as the sum,

$$\tilde{C}^{j}_{i}(y) = \sum_{p=1}^{N^{j}_{p}(y)} \tilde{c}^{j}_{i,p}(y). \tag{2}$$

Here $N^{j}_{p}(y)$ represents the scientist's total publications up to year y. The measure is the scientist's cumulative citations measured in units of the mean citation baseline $\langle c^{j}_{Y}(y)\rangle$. For a given researcher, i, the time variable y runs from the first year $y^{j}_{i,0}$ he/she published in j to the arbitrary census year Y. Due to the finite citation life cycle of most publications [26], as long as the difference between Y and y is sufficiently long, then the publication p should have a relative stable ranking amongst the publications from its journal-year cohort. In our citation analyses we require the difference $Y - y$ to be at least 7 years. As such, $\tilde{C}^{j}_{i}(y)$ is a robust measure of cumulative citation impact. Additional methods have

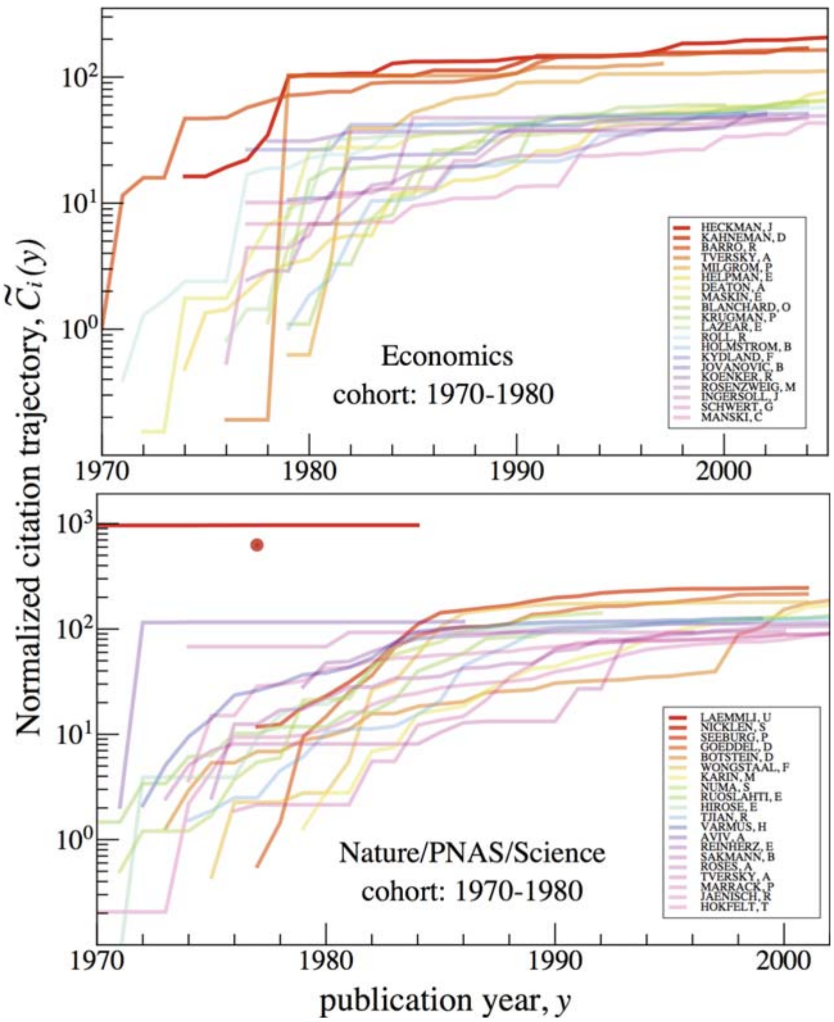

Figure 1 Top-cited scientists within the economists and natural sciences journal sets. Top-20 researchers, ranked by $\widetilde{C}$, who had their first publication in the time-period cohort 1970-1980. A trajectory terminates in the last observed year in which there was a publication within the journal set, and so a single dot represents a researcher profile with only a single publication. The citation census year *Y* was 2012 (economics) and 2009 (Nat./PNAS/Sci.). Hence using a 7 year window to allow the citations to properly accrue, only publications published prior to 2005 for economics and 2002 for Nat./PNAS/Sci. are shown.

also been developed to account for variable team size by further normalizing by coauthor number, thus providing a way to aggregate scientists from varying time, discipline, and even sub-disciplines [38, 39]. In a very general sense, this detrending approach can be easily applied to other competitive arenas, such as professional sports, where success rates can be explicitly era dependent [40].

Figure 1 shows $\widetilde{C}_i^j(y)$ trajectories for top-ranked researchers entering the journal sets over the decade 1970-1980 (see Figures S1 and S2 in Additional file 1 for researcher rankings using more recent time windows). In the case of economics there appears to be a greater level of separation (divergence) among the top ranked researches as qualitatively indicated by the gap between the highest-cited scientists (red curves) and the others. Each citation trajectory terminates at the year of the final publication within the journal set. In this way, a single dot corresponds to a scientist with a single publication. Figure 1 begins to

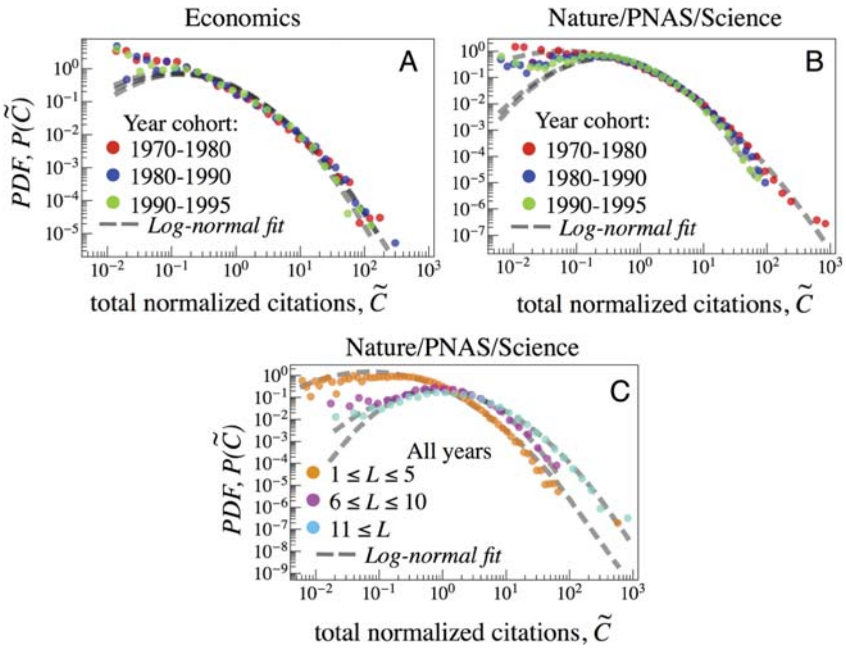

Figure 2 Skewed citation impact distributions. The right-skewed $P(\tilde{C})$, which range across more than 4 orders of magnitude, illustrate the wide range of outcomes in scientific winner-takes-all prestige competitions [1, 41]. To account for censoring bias we show the $P(\tilde{C})$ for the economics arena **(A)** and for the Nat./PNAS/Sci. arena **(B)** by considering non-overlapping scientist cohorts according to when each scientist entered a given arena by conditioning on his/her first publication being in the indicated time window. In **(C)** we show the $P(\tilde{C})$ conditional on the career length within the arena. The dashed grey best-fit curves are calculated using the log-normal distribution maximum likelihood estimator.

provide an answer to our preliminary questions, showing that the group of highest-cited scientists are a mixture of individuals whose accomplishments range from a single, monumental, contribution to persistent stream of high-impact publications, and everything between. However, as we will see below, despite this variability in the paths of ascent, there are remarkable statistical regularities in the distribution of $\tilde{C}_i^j$ across all researchers in each j.

To better understand the relative frequency of 'superstars' we calculated the distribution of normalized career citation counts $P(\tilde{C})$ using logarithmically sized bins to account for the broad distribution of $\tilde{C}_i^j$ values. Because $\tilde{C}_i^j$ controls for the average citation count of papers published within a specific year cohort, it is particularly well-suited for comparing achievements which occurred across a broad time range. Figures 2(A, B) each show three $P(\tilde{C})$ distributions, one for each of the cohorts indicated in the legend. Figure 2(C) shows conditional distributions $P(\tilde{C}|L)$, where L is the length of time between the first and last publication of author i in the journal set j,

$$L_i^j \equiv y_{i,f}^j - y_{i,0}^j + 1. \quad (3)$$

Interestingly, in each panel the aggregate success distribution is well-described by a log-normal distribution,

$$P(\tilde{C}) \propto \tilde{C}^{-1} \exp\left[-(\ln \tilde{C} - \mu)^2/2\sigma_{LN}^2\right], \quad (4)$$

Table 2 Summary of the Gini index (G) and top-1% share ($f_{1\%}$)

Journal set j	Cohort entry years	$G(\tilde{C})$	$f_{1\%}(\tilde{C})$	$G(N_p)$	$f_{1\%}(N_p)$
Economics	1970-1995	0.80	0.23	0.54	0.09
	1970-1980	0.83	0.26	0.56	0.10
	1980-1990	0.79	0.21	0.55	0.09
	1990-1995	0.74	0.19	0.47	0.07
Nat./PNAS/Sci.	1970-1995	0.69	0.18	0.46	0.10
	1970-1980	0.74	0.22	0.53	0.12
	1980-1990	0.67	0.15	0.45	0.08
	1990-1995	0.63	0.12	0.35	0.06

Inequality measures are calculated from the distribution of citation impact, $P(\tilde{C})$, and from the distribution of productivity, $P(N_p)$, for the cohorts of scientists whose first publication occurred in the indicated time intervals.

with varying location parameter μ and shape parameter σ, estimated using the log-normal distribution maximum likelihood estimator method. For small $\tilde{C}$ the log-normal fit has larger deviations from the empirical data due to fluctuations in the lower bound of $\tilde{C}$ arising from variability in the value of $\langle c^j_Y(y)\rangle$. Moreover, the poor fit for small $\tilde{C}$ further indicates that the aggregate empirical distributions are likely mixtures of underlying log-normal distributions with slightly varying shape and location parameters.

For example, in the 1980-1990 Economics cohort in Figure 2(A) we calculate $\mu = 0.23$ and $\sigma_{LN} = 1.53$ and for the 1980-1990 Nat./PNAS/Sci. cohort in Figure 2(B) we calculate $\mu = 0.30$ and $\sigma_{LN} = 1.25$. For contrast, the subset of Nat./PNAS/Sci. scientists in Figure 2(C) with $L \geq 11$ (with $\langle L\rangle = 20$, $\langle N_p\rangle = 6.8$ and $\langle\tilde{C}\rangle = 8.3$) have parameters $\mu = 1.31$ and $\sigma_{LN} = 1.26$. These values can be used to model the growth of $\tilde{C}$ using Gibrat's stochastic (proportional) growth model, $\Delta\tilde{C}_t = \tilde{C}_{t-1}(1 + \eta)$, where η is white noise with mean and standard deviation depending on the log-normal counterparts, μ and σ_{LN}. The limiting distribution of this multiplicative process is the log normal distribution (see [42] for recent empirical and theoretical results on firm growth that provides an appropriate starting point for the modeling of researchers' publication portfolios as companies in the small size limit).

To provide additional intuition regarding the level of 'inequality' within these citation distributions, we calculated the Gini index G as well as the citation share $f_{1\%}$ of the top 1% of researchers in each $P(\tilde{C})$. For example, for the 1970-1980 cohort we observe $G = 0.83$ (economics) and $G = 0.74$ (Nat./PNAS/Sci.) and found that the top 1% of researchers (comprised of 17 and 139 researchers, respectively) held a significantly disproportionate share of 26% and 22% of the total $\tilde{C}$ aggregated across all researchers in each distribution. Table 2 shows the $G(\tilde{C})$ and $f_{1\%}(\tilde{C})$ for each cohort group, which indicate for both journal sets a decreasing trend in the citation inequality over time. We note that our calculations do not control for the increasing prevalence of large collaborations in science [3]. Therefore, because there are correlations between the number of coauthors and the average citations a publication receives [22], and because we did not control for multiple counting of single publications in the calculation of the total $\tilde{C}$, it is difficult to assess whether the difference between the inequality values calculated for economics (where coauthorship effect is weak because the number of coauthors is typically small) and for natural sciences is attributable to this feature of the data.

For comparison, a recent analysis of US research funding at the institutional level provides a different picture, indicating a slow but steady increase in the Gini index across U.S. universities over the last 20 years, with current estimates of the Gini inequality index for

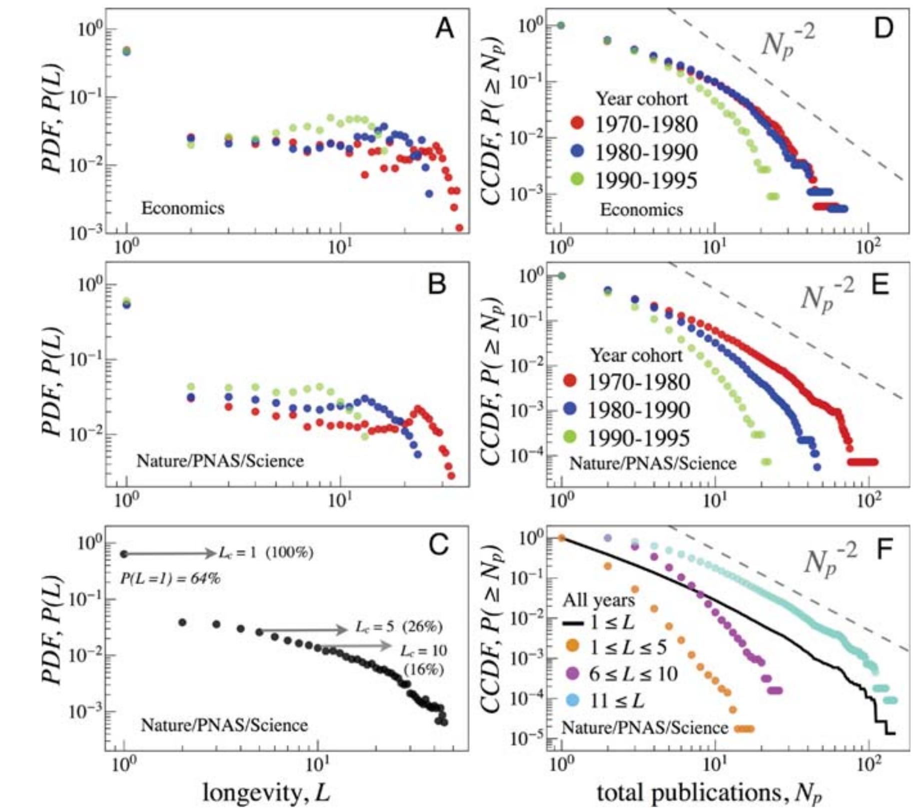

Figure 3 Competitive arenas in science. The right-skewed distributions of scientist longevity L and productivity N_p are the starting point for understanding the skewed success distributions in science. Panels **A** (Economics) and **B** (Nat./PNAS/Sci.) address censoring bias in the longevity distributions by considering separately the cohorts of scientists who entered the Nat./PNAS/Sci. arena in the indicated time window. Panel **C** (Nat./PNAS/Sci.) shows the unconditional aggregate longevity distribution. Panels **D/E/F** show $P(\geq N_p)$, the complementary cumulative distribution function (CCDF) of total publications N_p. Panels D/E are analogs of panels A/B, showing the fixed cohorts of researchers who entered the respective journal arena with their first publication in the indicated time window. Panel F shows the $P(\geq N_p|L)$ distributions conditioned on L, which indicate that even within the set of 'iron horse' researchers with longevity $L_i \geq 11$ the distribution is still extremely broad. To guide the eye and emphasize the curvature in $P(\geq N_p)$, which is not consistent with a power-law distribution, we plotted a curve proportional to N_p^{-2}.

university expenditure around $G \approx 0.8$ [7]. This increasing trend has also been noted in data measuring the share of the top 1% individuals in terms of U.S. income, which has increased from roughly 10% to 20% over the last half century; nevertheless, the 2010 U.S. income Gini coefficient reported was $G = 0.4$ [43], significantly less than what we observed for these citation distributions.

Success is typically assumed to be strongly correlated with career longevity, but to what degree does this assumption hold? In Figure 2, we conditioned the distributions on L_i and find that $P(\tilde{C}|L)$ is still well-described by a log-normal distribution, even after controlling for censoring and survivor bias. Hence, the correlation is somewhat weak, because even among researchers publishing in Nat./PNAS/Sci. for $L \geq 11$ years, the citation distributions still span a huge range, from $\tilde{C} \sim 10^{-1}$ to $\tilde{C} \sim 10^3$, with the maximum value being roughly 100 times larger than the characteristic mean value $\langle \tilde{C} \rangle \sim 10^1$.

Figures 3(A, B) show the longevity distributions $P(L)$ conditioned on the first publication being within a specified time window. Remarkably, roughly half the scientists enter and exit the arena in a single year ($L_i^j = 1$), likely with a single publication. At the other end of the distribution, as indicated by the systemic shift in the tail across cohorts, a relatively small set of prolific scientists steadily publish within the arena throughout their scientific careers. The tail of the distribution, beginning around the peak in the far right of the distribution, consists of scientists sustained activity in j for longer than a decade, representing roughly 15-20% of the researchers analyzed. Aggregating across cohorts, Figure 3(C) shows that roughly 64% of authors enter this arena for the minimum time span of 1 year, with only 16% of the entrants publishing over a period $L_i \geq 10$ years.

While Figures 3(A-C) illustrate how long scientists stay active these high-impact arenas, Figures 3(D-F) show the productivity distributions $P(\geq N_p)$ for the same datasets shown in (A-C). The top 20% of the distribution corresponds to individuals publishing roughly five publications or more, signifying a rather broad productivity distribution even amongst the researchers with $L \geq 11$. Indeed, comparing $P(\geq N_p|L)$ conditioned on career length in Figure 3(F), there is a rather large range in N_p, e.g. from 3 to more than 100 publications for the subset with $L \geq 11$. We also note that none of the productivity distributions are consistent with Lotka's productivity law, $P(\geq N_p) \sim N_p^{-\lambda}$, for any value λ.

In order to compare the inequality levels for citation impact to productivity, we also calculated G and $f_{1\%}$ for each productivity distribution $P(\tilde{N}_p)$. For example, for the 1970-1980 cohort we calculated $G = 0.56$ (economics) and $G = 0.53$ (Nat./PNAS/Sci.), finding that the top 1% of researchers (comprised of 17 and 139 researchers, respectively) had a share of 10% and 12% of the total publications. Table 2 shows the $G(N_p)$ and $f_{1\%}(N_p)$ for each cohort group, which like the citation inequality counterparts $G(\tilde{C})$ and $f_{1\%}(\tilde{C})$, suggests that productivity inequality is also becoming more equitable over time. However, it is worth noting that citation inequality is substantially larger than publication inequality for each cohort group, arising from the fact that all publications are measured equally and their value does not increase over time, in contrast to citations which accrue over time.

We conclude this section by noting the similarity and differences between the analysis performed in ref. [38]. First, the career citation share and paper share measures defined in [38] normalizes by the number of coauthors (dividing the credit among them equally). Also, a statistical method to eliminate 'unfinished' careers was implemented in [38] but was not used here. Hence, the results in this section, which represent finished and unfinished careers pooled together, neglect the censoring bias arising from including unfinished careers.

2.2 Decreasing waiting times as quantitative evidence of cumulative advantage

In the previous section we showed that the distributions of impact, productivity, and longevity are consistent with a highly competitive 'winner takes all' system. In this section we shift to the longitudinal perspective of researcher trajectories. The schematic in Figure 4(A) emphasizes the sequence of accomplishments as they might occur across a scientist's complex backdrop of career phases (grad student/postdoctoral fellow → assistant professor → tenured faculty). These career phases are characterized by varying roles in the research process, shifts in research interests, and the accumulation of various institutional responsibilities.

Our approach is to measure the longitudinal patterns in the sequence of inter-publication waiting times of individual researchers. It is important to note that we are not analyzing the complete publication profile of each researcher, but rather, just the set

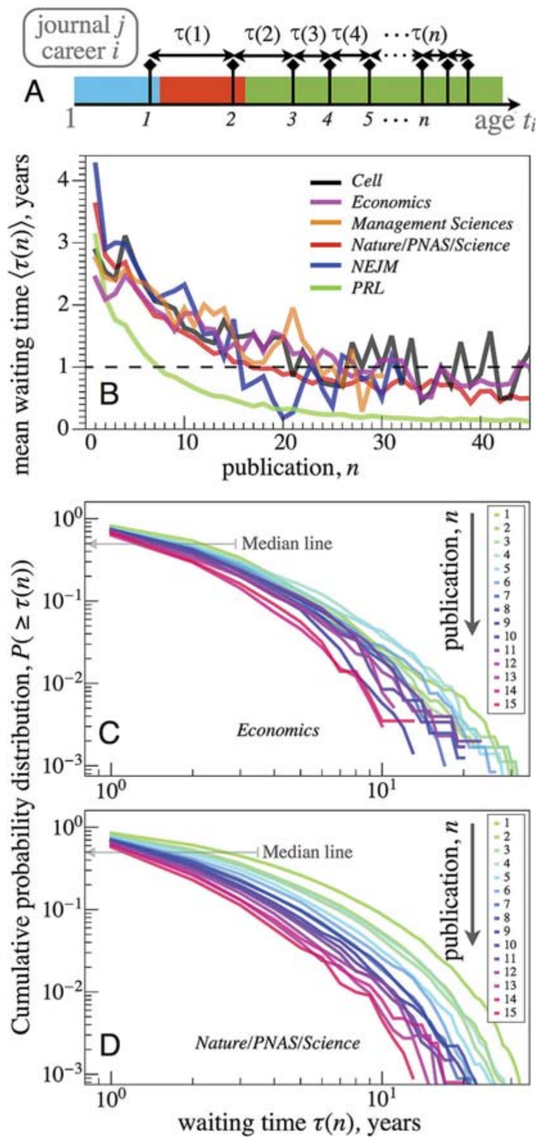

Figure 4 Decreasing inter-publication waiting time $\tau(n)$ is quantitative evidence for cumulative advantage in science. **(A)** Schematic of a science career, where major accomplishments sustain career growth. Specifically, publications in high-impact journals serve as a record of scientists capitalizing on opportunities for success, and the duration $\tau_i^j(n)$ between a scientist's success n and success $n+1$ provide a quantitative method for analyzing cumulative advantage. We search for quantitative evidence of self-reinforcing social mechanisms by analyzing productivity patterns in specific journal sets that are highly competitive and widely targeted. **(B)** The average waiting time $\langle \tau^j(n) \rangle$ between publication n and publication $n+1$ shows a significant decreasing trend as an author continues to publish in a given journal set. A decreasing $\tau^j(n)$ between publications suggests that an advanced publication career (larger n) facilitates future publications by leveraging reputation, expertise, seniority, and other cumulative resources. The values of $\langle \tau^j(1) \rangle$ are 2.9 yrs. (Cell), 2.4 yrs. (Econ.), 2.8 yrs. (Mgmt. Sci.), 3.6 yrs. (Nat./PNAS/Sci.), 4.3 yrs. (NEJM) and 3.1 yrs. (PRL). The journal PRL exhibits a more rapid decline in $\tau(n)$ because of possible rapidity in successive publications (often by large high-energy experiment collaborations that publish many publications together in a single issue). Only research profiles with $L \geq 5$ years and $N_p \geq 5$ are included in the calculation of these inter-event waiting-time curves. In order to reduce censoring bias arising form careers that started before the beginning of each data sample, we only included trajectories with the first publication year $y_{i,0}^j \geq 1970$ for the natural and management sciences and $y_{i,0}^j \geq 1960$ for the economic sciences. **(C, D)** Complementary cumulative probability distribution, $P(\geq \tau(n))$, for publications $n = 1, \ldots, 15$ in (C) the Economics and (D) Nat./PNAS/Sci. journal sets. The distributions are right-skewed, indicating the possibility of a relatively long waiting time $\tau(n)$ for all n. However, by $n = 10$ the observed likelihood of waiting 3 or more years, $P(\geq 3|n = 10)$, falls to roughly 0.2 for both Econ. and Nat./PNAS/Sci.

of publications within each journal set j. Given the significant incentives for publishing in top journals, both in terms of prestige [1, 41] and financial benefits [44], we assume that 'if a researcher *could* publish in one of these journals, he/she *would*.' In this regard, the information contained in the waiting times between successive publications can provide quantitative insight into the workings of cumulative advantage.

For each i in j we define a sequence of waiting times, $\tau_i^j(n)$, for which the nth entry is the number of years between his/her publication n and publication $n+1$ in a given journal set j. For example, the average time $\langle\tau^j(1)\rangle$ between an author's first and second publication in both NEJM and Nat./PNAS/Sci. is roughly four years, whereas in the biology journal Cell and the physics journal PRL, the initial mean waiting time is closer to three years.

Figure 4(B) shows that the average $\langle\tau^j(n)\rangle$ decreases significantly with increasing n for each journal arena analyzed. Indeed, by the around the 10th publication the waiting time $\tau^j(10)$ has decreased to roughly 1/2 of the initial waiting time $\tau^j(1)$. Moreover the rate of publications becomes roughly one per year after the 30th publication in the economics journal set, and one per year after the 20th publication in the non-physics journal set, and on average one per year after the 10th publication in PRL.

In order to provide new insights beyond what was already shown in [38], we have extended the waiting-time analysis to the research domains of economics and management science, and have also analyzed the distribution of waiting times $P(\geq \tau^j(n))$ which are shown in Figures 4(C, D) for $n = 1, \ldots, 15$. Notably, the systematic shift towards smaller $\tau^j(n)$ is not only reflected by the median and the mean $\tau^j(n)$ value, but is also visible across the entire distribution. Indeed, by $n = 10$ the observed likelihood $P(\geq 3|n = 10)$ of waiting 3 or more years until the next publication (3 years being a characteristic time scale associated with both a scientific project and a scientific collaboration), falls to roughly 0.2 for both Econ. and Nat./PNAS/Sci. A factor likely contributing to this systemic trend is the steady exponential growth in the total number of publications per year (recently measured for physics and cell biology to be around 5% growth per year [26]), as well as a slow but substantial 1% to 5% exponential growth in coauthorship size over time depending on the discipline [3], both of which could account for an overall decrease in publication waiting times.

The significant smaller values for the journal PRL largely reflects the large variations in team size as well as the type of research design - experimental and theoretical - occurring in physics. To elaborate, we ponder three basic pathways to publishing more than one publication in this high-impact journal per year. The first pathway involves a theoretical physicist with a very inspiring year - e.g. Albert Einstein's 1905 'Annus Mirabilis' - who is able to rapidly publish more than one (relatively short, $\leq$6 pages) letters in succession. This pathway, however, is likely unsustainable over the long run. The second pathway involves an experimental physicist working at a large particle collider or national laboratory, working in large teams that publish results with 500 or more coauthors. In this situation, a scientist in a top management position or involved with a critical experimental process may even be able to consistently publish multiple PRL articles per year; For a peculiar example consider L. Nodulman who has 388 PRL publications, but with on average 670 coauthors per publication! The third pathway, present to all scientists independent of discipline, reflects a mixture of the first two pathways, whereby a scientist is embedded in an efficient medium-sized team environment and capitalizes on collaboration spillovers, thereby consistently producing highly-cited publications. We should also mention that

PNAS offers a streamlined publication track ('contributed paper') for select US National Academy of Sciences members, an additional idiosyncratic and rare pathway, which nevertheless contributes to the surprisingly large number of scientists that have numerous publications in the Nat./PNAS/Sci. journal set.

Overall, Figure 4 provides evidence that cumulative advantage plays a strong role when it comes to publishing in elite journals. In fact, the mean waiting time, which can be empirically measured using publication data, also has a simple analytic relation to a position-dependent progress rate $g(n) = 1/\langle\tau(n)\rangle$ within a Poisson process framework, where $g(n)$ is the probability of moving from position n to $n+1$ in a unit time interval. This theoretical model has been tested on both scientific and sports career data, with the interesting feature that small modifications to the progress rate $g(n)$ for small n (early career transition rates) can lead to either a bimodal or a truncated power-law career longevity distributions [25], offering insight into the potential impact of career sustainability policies aimed at early-career researchers.

2.3 A decreasing longitudinal citation trend

In this section we investigate the longitudinal citation impact trends for the publications in each researcher profile. This analysis is related to the delicate topic of 'career predictability' [45–47], but is distinct in the sense that we focus exclusively on the citation impact *within the most prestigious journals* and *relative* to his/her own citation baseline. Hence, as a significant number of publications within each scientist's rank-citation profile [48, 49] are missing from our analysis, it is important to note that we do not contend that the citation trends within the high-impact journal set are representative of the trend within the scientist's entire publication portfolio.

We focus on the publication trajectory of individuals within select high-impact journals, acknowledging that it is likely to reflect factors beyond just the inherent citation impact of his/her average research output. One possibility is that there is no significant change in the citation impact of a researcher's publications over time. A second possibility is that there is an increase in the citation impact with each subsequent publication. This increasing trend is consistent with a researcher being able to leverage prior success to improve their research resources [29] and to leverage reputation within the community to increase their base citation rate [26]. A third scenario is a decrease in the citation impact over time. This negative trend is consistent with an opportunity premium that is provided to accomplished scientists via cumulative advantage, such that new opportunities arrive at effectively a 'lower cost' than the base 'entry cost'.

In order to investigate the longitudinal variation in the citation impact, we map the citation count $c^j_{i,p,y}(n)$ of the nth publication p of researcher i to a z-score,

$$z_i(n) \equiv \frac{\ln c^j_{i,p,y}(n) - \langle \ln c^j_y \rangle}{\sigma[\ln c^j_y]}, \tag{5}$$

which allows for a comparison of citation counts across time. The z-score of the log-citation count in Eq. (5) is measured relative to the mean ($\langle\cdots\rangle$) and standard deviation ($\sigma[\cdots]$) of the logarithm of the citations for a given journal set, j, in a given year, y. This follows naturally since the logarithm of a log-normally distributed variable is a normally distributed variable ($z \sim N(0,1)$), making the z-score an appropriate statistical measure.

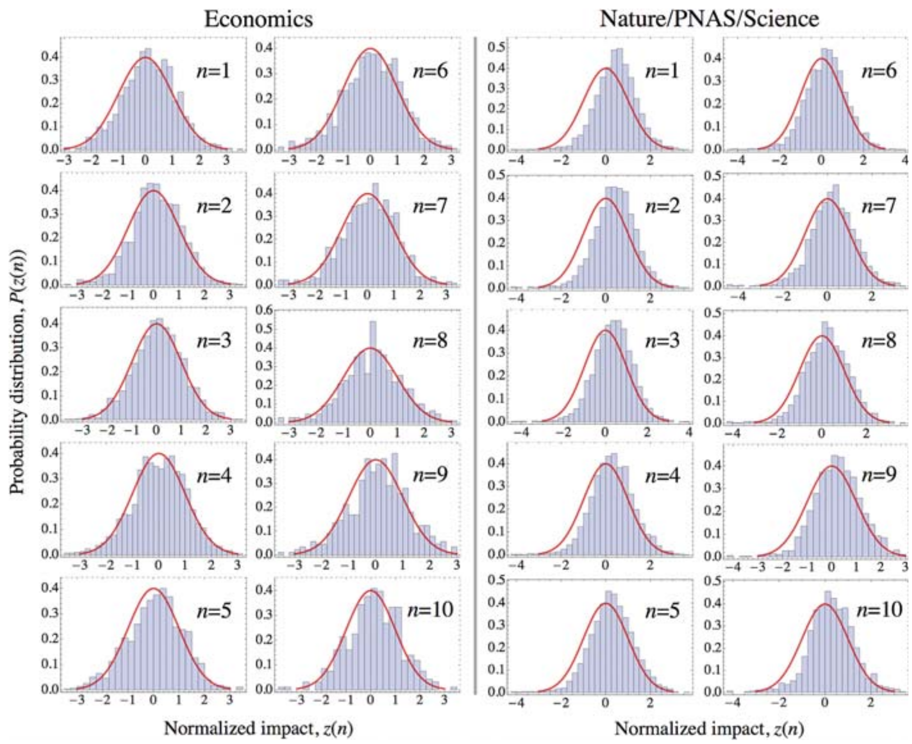

Figure 5 Empirical distribution of citation impact values conditioned on publication number *n*. We aggregate the normalized citation *z* values of researcher profiles with first publication year $y^j_{i,0} \geq 1970$ for Nat./PNAS/Sci. and $y^j_{i,0} \geq 1960$ for the economic sciences, and with $L_i \geq 5$ and $5 \leq N_p \leq 20$. Each panel shows the probability distribution $P(z(n))$ conditioned on publication number $n = 1, \dots, 10$. The *z*-scores represented by each $P(z(n))$ represent a subset of the aggregate set of *z* values, independent of L_i and N_p. Because the unconditional distribution of *z* values is approximately normal with mean 0 and with units of the standard deviation ($\sigma_z = 1$), we also plot a normal distribution Normal(0, 1) in each panel for reference (red curve).

We use the convention of replacing c_p by 1 for publications with zero citations; similarly, the mean $\langle \ln c^j_y \rangle$ and standard deviation $\sigma[\ln c^j_y]$ within each journal set are also calculated excluding publications with no citations. This method of dealing with the logarithm of zero has a negligible overall effect, since only 1.5% of publications over the time period 1970-2002 had 0 citations in the census year 2009 for the Nat./PNAS/Sci. journal set, and publications in the economics dataset had only twice this frequency.

Figure 5 shows the distributions of $z_i(n)$ conditioned on the publication number $n = 1, \dots, 10$ and restricting to researchers with $L_i \geq 5$ and $5 \leq N_p \leq 20$. For example, $P(z(1))$ is the distribution of *z*-scores for the set of first publications, $P(z(2))$ is the distribution for the set of second publications, and so on. Each $P(z(n))$ is approximately normal, with a mean and standard deviation that deviates only slightly from the baseline Normal(0,1) distribution (red curve) shown for visual comparison.

Next, in order to account for author-specific heterogeneity before we aggregate citation trajectories across scientists, we centered the *z*-score around the mean value $\langle z_i \rangle \equiv N_p^{-1} \sum_{n=1} z_i(n)$ calculated for the N_p publications of a given scientist *i*. As a result, we obtain the relative citation impact trajectory,

$$\tilde{z}_i(n) \equiv z_i(n) - \langle z_i \rangle. \tag{6}$$

Table 3 Summary statistics for two aggregate regression models

Journal set	N_p	A	B	S	p-val.	N_{fit}	R^2
Economics	4-9	1,090	0.17(3)	–0.046(4)	$\mathbf{1 \times 10^{-5}}$	9	0.93
Shuffled	4-9	21,800	–0.003(6)	0.0001(1)	0.68	9	0.03
Economics	10-20	373	0.17(2)	–0.021(4)	$\mathbf{5 \times 10^{-4}}$	10	0.87
Shuffled	10-20	7,460	0.01(1)	–0.002(2)	0.23	10	0.17
Mgmt. Sci.	5-10	262	0.22(9)	–0.05(1)	$\mathbf{6 \times 10^{-3}}$	10	0.63
Shuffled	5-10	5,240	–0.01(3)	0.004(4)	0.40	10	0.09
Mgmt. Sci.	11-20	62	0.5(1)	–0.07(2)	$\mathbf{4 \times 10^{-3}}$	10	0.68
Shuffled	11-20	1,240	0.03(2)	0.005(4)	0.20	10	0.19
Nat./PNAS/Sci.	5-10	3,953	0.15(2)	–0.035(4)	$\mathbf{8 \times 10^{-6}}$	10	0.93
Shuffled	5-10	79,060	–0.006(8)	0.002(1)	0.28	10	0.16
Nat./PNAS/Sci.	11-20	847	0.23(3)	–0.032(4)	$\mathbf{10^{-4}}$	10	0.88
Shuffled	11-20	16,940	0.02(1)	–0.003(1)	0.05	10	0.36

Journal set	N_p	N_d	b	s	p-val.	A	R^2
Economics	4-9	6,183	0.19(3)	–0.053(7)	**0**	1,090	0.012
Economics	10-20	3,730	0.17(3)	–0.022(6)	$\mathbf{3 \times 10^{-4}}$	373	0.005
Mgmt. Sci.	5-10	1,710	0.26(4)	–0.07(1)	**0**	262	0.020
Mgmt. Sci.	11-20	620	0.48(9)	–0.07(2)	$\mathbf{10^{-4}}$	62	0.042
Nat./PNAS/Sci.	5-10	26,010	0.19(1)	–0.048(3)	**0**	3,953	0.013
Nat./PNAS/Sci.	11-20	8,470	0.23(2)	–0.032(4)	**0**	847	0.013

(Top) The regression model (ii) given by Eq.(8): A denotes the number of individual careers that were aggregated for each mean impact trajectory $\langle \tilde{z}(n) \rangle$. B and S are estimated using ordinary least squares, along with the F-test p-value, the number N_{fit} of data points, and the R^2 correlation value. The number in parentheses represents the standard error in the last digit shown. The 'shuffled' values correspond to the parameter estimations using our citation shuffling scheme (conserving the empirical citation distribution) that also allows for an increase in the sample size by a factor of 20). We also include the management science careers for comparison since the dataset contained a sufficient number of researcher profiles to analyze. Bold-faced p-values indicate the regressions with $p \leq 0.01$. (Bottom) The fixed-effects linear regression model (iii) (implemented by the function 'xtreg, vce(robust) fe' in STATA11) given by Eq. (9). We used the 'vce(robust)' Huber-White variance estimator to account for possible heteroscedasticity in the model errors. N_d denotes the number of observations, b and s are the coefficient estimates of the fixed-effects model (value in parenthesis is the robust standard error in the last significant digit), and p-val. corresponds to the model F-statistic $F(1, A-1)$.

This normalization also helps in controlling for latent effects arising from disciplinary variation within each j that can affect the citation potential of a paper over time. Using these standardized $\tilde{z}_i(n)$ trajectories, we pooled the data across scientists, noting that $\tilde{z}_i(n)$ is still measured in normalized units of the standard deviation $\sigma_{\ln c}$.

We also separated the researcher data into two sets of profiles, one with medium N_p and the other with relatively large N_p, requiring in both cases that $L_i \geq 5$ so that increasing n is more likely to correlate with increasing time. In order to reduce censoring bias arising from careers that started before the beginning of each data sample, we only analyzed trajectories with the first publication year $y^j_{i,0} \geq 1970$ for Nat./PNAS/Sci. and $y^j_{i,0} \geq 1960$ for the economic sciences.

For both disciplines and for each N_p subset we observed on average a negative trend in $\tilde{z}_i(n)$. We show this negative trend at two levels of aggregation outlined below, first at the individual level in method (i), and then at the systemic level in methods (ii) and (iii). Table 3 shows the summary statistics and parameter estimates for models (ii) and (iii).

(i) In order to analyze trends at the researcher level, we first analyzed each individual $\tilde{z}_i(n)$ separately by performing an ordinary least squares parameter estimation of the parameters of the basic linear model

$$\tilde{z}_i(n) = b_i + s_i n + \epsilon. \tag{7}$$

Figure 6 shows the cumulative distribution $P(\leq s_i)$ for four scientist subsets (see Fig. S3 in Additional file 1 for the analogous plots for the management science researcher profiles). In each case, the average value $\langle s_i \rangle$, indicated by the vertical blue line, is negative at the indicated p-value shown within each sub-panel (using the 1-sided z-statistic with the null hypothesis that $s = 0$). The $P(\leq 0)$ value, ranging between 60% to 70% across the four panels, indicates the excess proportion of the population with negative s_i. The asymmetry towards statistically significant negative s_i values is even more pronounced. For example, consider the asymmetry in the large N_p subsets: of the 373 economics profiles we analyzed, only 2 (0.5%) had p-val. < 0.01 and $s_i > 0$ whereas 18 (5%) had p-val. < 0.01 and $s_i < 0$; of the 847 Nat./PNAS/Sci. profiles we analyzed, only 8 (1%) had p-val. < 0.01 and $s_i > 0$ whereas 60 (7%) had p-val. < 0.01 and $s_i < 0$.

(ii) In the first aggregate method we calculated the mean citation impact z-score $\langle \tilde{z}(n) \rangle$ across all researcher profiles within j for a given n, and then performed the ordinary least squares parameter estimation of the analogous aggregate model,

$$\left\langle \tilde{z}(n) \right\rangle = B + Sn + \epsilon. \quad (8)$$

We plot $\langle \tilde{z}(n) \rangle$ (solid black curve) and the best-fit regression (dashed green line) for each researcher subset in Figure 6. To give an example, Figure 6(A), which refers to scientists in the Nat./PNAS/Sci. subset with between 5 and 10 publications, shows that the mean impact trajectory decreases by $S = 0.035 \pm 0.004$ - roughly 25% of $\langle \tilde{z}(1) \rangle$ - with each subsequent publication. This means that after the 4th publication, the relative impact typically is 'subpar' *with respect to a given scientist's mean* $\langle z_i \rangle$. Interestingly, for the cohort of scientists in Figure 6(B) with between 11 and 20 publications, the impact trajectory starts at a higher value, and since the slope is approximately equal to the slope in panel (A), the publications do not become subpar until after the 7th publication. We observe the analogous trends for the economics journal set. However, the S value for the relatively low-N_p economics subset in panel (C) is significantly more negative than the value estimated for the high-N_p researcher set in panel (D).

(iii) The previous model doesn't account for the fact that observations are not independent (since $\tilde{z}(n)$ values within each subset n also depend on i), and that the data are unbalanced (since N_p vary across researchers in each dataset). Hence, we apply a hierarchical approach in this second aggregate method by running an unbalanced fixed-effects regression with standard errors clustered by author i,

$$\tilde{z}_{i,p} = b + sn_{i,p} + \epsilon_{i,p}, \quad (9)$$

implemented using the STATA11 regression 'xtreg, vie(robust) fe'. We used the 'vce(robust)' option to implement the 'Huber/White/sandwich' estimate of the standard errors in order to account for possible heteroscedasticity in $\tilde{z}_{i,p}$. This approach also accounts for time-invariant characteristics of the authors. The parameter estimates in Table 3 of this hierarchical regression model show that the estimated coefficients B and b estimated in Eqs. (8) and (9) are consistent in value. The main difference is the explained variance provided by each method. Method (ii) indicates a large R^2 because it eliminates the variance in $\tilde{z}$ by representing only the systemic average, whereas the low R^2 value in method (iii) is a reminder that there are important hidden covariates affecting citation impact that are not captured by this simple model. Other covariates which have been shown

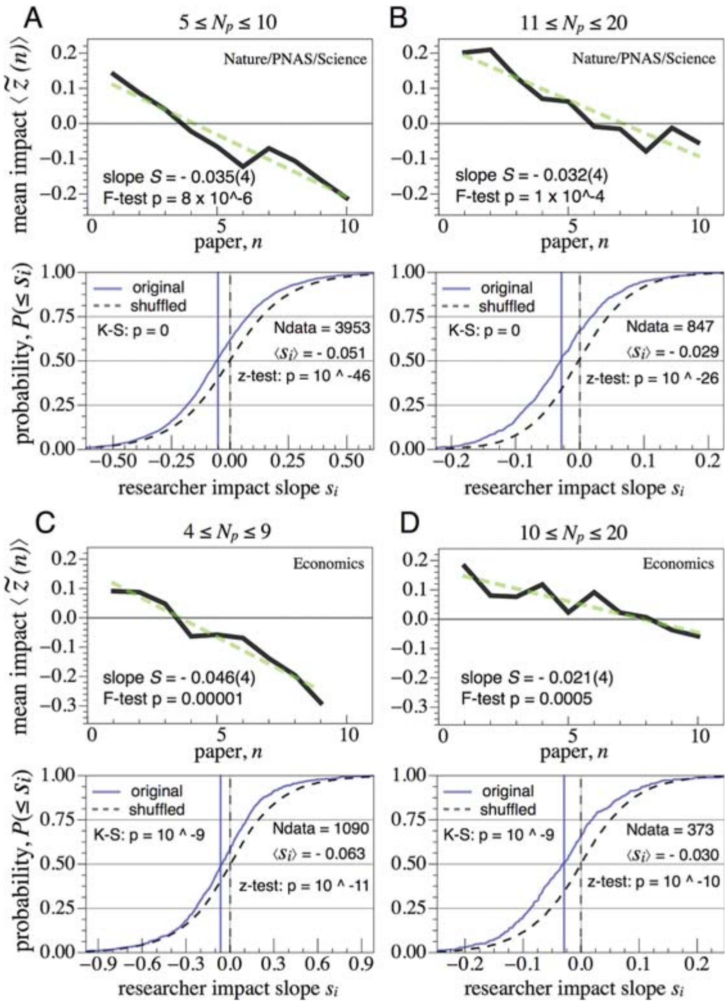

Figure 6 Evidence consistent with confirmation bias and a counter-effective role of cumulative advantage. We test whether the relative citation impact $\tilde{z}_i(n)$ decreases, increases, or is independent of n. While repeated publication in a highly competitive journals reflects the underlying quality of the researcher, it also indicates a strong role played by other factors such as author/institutional reputation and social ties with the journal editors and the referee base, and in the case of PNAS, membership in the US National Academy of Sciences. **(A)** Scientists with between 5 and 10 publications in the Nat./PNAS/Sci. arena. **(B)** Scientists with between 11 and 20 publications in the Nat./PNAS/Sci. arena. **(C)** Economists with between 4 and 9 publications in the top economics journal set arena. **(D)** Economists with between 10 and 20 publications in the top economics journal set arena. (A-D) For each cohort analyzed, the top panel shows a significant negative trend in $\langle\tilde{z}(n)\rangle$ (black curve) with each successive publication. Linear regression of each $\langle\tilde{z}(n)\rangle$ is shown by the dashed green line, with the best-fit slope and regression F-test p-value listed in each panel. In the lower half of each panel we show the empirical cumulative distribution $P(\leq s_i)$, and list the number of trajectories analyzed and the mean value $\langle s_i\rangle$ (indicated by the vertical solid blue line). For comparison, we also plot the $P(\leq s_i)$ for the shuffled data (dashed black curve), with the mean shuffled value (vertical dashed gray line). We apply the Kolmogorov-Smirnov test between the empirical and shuffled distributions, and for each panel we list the p-values that confirm that the underlying s_i values belong to different distributions. Only research profiles with $L \geq 5$ years were analyzed. In order to ensure that the relative citation impact z_p of a given publication had sufficient time to stabilize within the journal set dataset, only publications published prior to 2002 for Nat./PNAS/Sci. (since the publication citation counts used were current as of census year 2009) and 2005 for Economics (since citation counts used were current as of census year 2012) were analyzed. In order to reduce censoring bias arising form careers that started before the beginning of each data sample, we only included trajectories with the first publication year $y^j_{i,0} \geq 1970$ for the Nat./PNAS/Sci. and $y^j_{i,0} \geq 1960$ for the economic sciences.

to explain citation impact are team size [22], institutional prestige [32], conceptual novelty [23], and author reputation [26].

Additionally, in order to check that our results are not affected by systematic sampling bias, we analyzed the same sets of impact trajectories in panels (A-D) using a shuffling method to destroy the author-specific correlations across time. To be more specific, for a given scientist i we conserved his/her number of publications within the dataset. However, we randomly assigned a c^j_y to each of his/her publications, replacing the true citation value with a randomly drawn c^j_y value from the same year y and journal set j. Because in our shuffling algorithm we sampled without replacement, this technique conserves the overall probability distribution $P^j_y(c)$ of citations within a given journal set within a given year, and hence $\langle \ln c^j_y \rangle$ and $\sigma[\ln c^j_y]$ also remain unchanged, as do each $P(z(n))$. This shuffling technique also permits an increase in the number of trajectories analyzed within each subsample since we can reshuffle the data numerous times. Hence, for each journal set we increased the sample size by producing 20 shuffled synthetic datasets, thereby increasing the number of trajectories we analyzed by the same factor.

With respect to method (i), we tested the likelihood that the original s_i values and the shuffled s_i values arise from the same distribution by applying the Kolmogorov-Smirnov test between the original and shuffled cumulative distributions, $P(\leq s_i)$. In each case the p-value is less than 10^{-8}, rejecting the null hypothesis that the two sets of s_i values belong to the same distribution (values reported within each sub panel of Figure 6). With respect to method (ii), we also tested the model in Eq. (8) for each shuffled $\langle \tilde{z}_i(n) \rangle$, finding no significant positive or negative trend (see Table 3 for F-test p-values). Altogether, the comparison of the shuffled and empirical trajectories confirms that our estimates of S and s_i are not sensitive to systematic sampling artifacts.

Figure 7 shows a scatter plot which allows for the visual comparison of four descriptive variables for each researcher trajectory: the impact score of the 1st publication $z_i(1)$, the trajectory slope s_i, the mean impact value $\langle z_i \rangle$, and the total number of publications $N_{p,i}$. This scatter plot indicates an overall negative relation between $z_i(1)$ and s_i, indicative of the difficulty in sustaining high-impact research as well as the lack of predictive information contained in early achievement, $z_i(1)$. To further investigate their relation, for each journal set we estimated the coefficients of the linear regression model, $s_i = \beta_0 + \beta_1 z_i(1) + \beta_2 \log_{10} N_{p,i} + \beta_3 \langle z_i \rangle$. Consistent with the scatter plot, we observed the coefficient for $z_i(1)$ to be negative ($\beta_1 = -0.14$ for Econ. and Mgmt. Sci. and -0.17 for Nat./PNAS/Sci., each estimate statistically significant at the $p \approx 0$ level). Consistent with the S values for the medium versus large N_p subsets, we also observed a positive coefficient for $\ln N_{p,i}$ ($\beta_2 = 0.08$ for Econ., 0.17 for Mgmt. Sci., and 0.10 for Nat./PNAS/Sci., each estimate statistically significant at the $p = 0.01$ level). In each regression the coefficient for $\langle z_i \rangle$ was not statistically significant and the adjusted R^2 was roughly 0.35.

3 Conclusion

What can data science offer to the science of science? By leveraging the rich longitudinal, geographic, and cross-sectional aspects of large publication and patent datasets, new insights into career growth amidst the unabating competition for scientific credit [50] can provide institutions and policy makers important knowledge on how to assess and react to paradigm shifts in science.

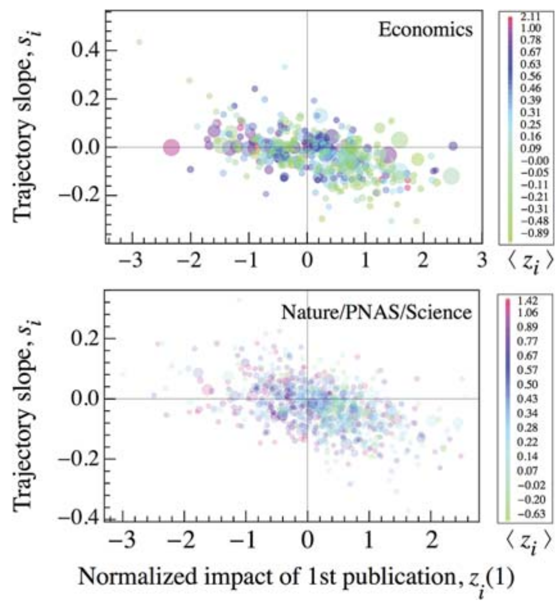

Figure 7 Visualizing the covariates underlying s_i. Scatterplot visualization of the impact score of the 1st publication $z_i(1)$, the trajectory slope s_i, the mean impact value $\langle z_i \rangle$ (color of the data point), and the total number of publications N_p (proportional to the size of the data point). These scatter plots demonstrate that there is an increased likelihood that a decreasing trend ($s_i < 0$) starts with a positive above-average citation value ($z_i(1) > 0$), indicative of how difficult it can be to consistently publish above-average research. A linear regression model indicates a negative relation between s_i and $z_i(1)$ and a positive relation between s_i and N_p (see discussion in text).

3.1 Success distributions in science

Here we have provided evidence that research careers exhibit the broad distributions of individual success characteristic of competitive systems in which cumulative advantage plays a key role. The inequality in research career activity in high-impact journals can be appreciated by considering the Gini coefficient calculated from the distribution of individual researcher productivity and impact. For example, pooling the Nat./PNAS/Sci. publication profiles that began within the period 1970-1995, we observed a Gini index $G = 0.46$ for publications and $G = 0.69$ for citations. For economics we observed even higher levels of inequality, with $G = 0.54$ for publications and $G = 0.80$ for citations. The fraction $f_{1\%}$ of the total output produced by the top 1% further demonstrates the disproportionate productivity levels even among scientists publishing in top ranked journals: $f_{1\%} = 0.09$ for publications and $f_{1\%} = 0.23$ for citations (economics), and $f_{1\%} = 0.10$ for publications and $f_{1\%} = 0.18$ for citations (Nat./PNAS/Sci.). Hence, it is important to note that the inequality amongst researchers is much greater when considering impact measures than for productivity measures. For perspective, the G values we calculated are larger than those observed for individual income in many developed nations of the world [43]. Nevertheless, with respect to individual achievement in science, we have provided evidence that the system became more equitable over the period 1970-1995.

3.2 On the role of cumulative advantage in academic career evaluation

The role played by the 'Matthew effect' is largely considered to be positive [24]. Indeed, cumulative advantage represents a 'positive' feedback mechanism that arises from the functionally meritocratic system of science, which aptly rewards scientists who succeed in producing high-quality research [51].

Using a reasonably large and representative number of career profiles that satisfied our censoring bias criteria, we provided quantitative demonstration of how cumulative advantage in the publication process emerges, showing that the time between publications in top journals decreases as function of how many publications a researcher has published in those journals. This decrease is evident not only in the mean waiting time, but as a systematic shift in the distribution of waiting times towards smaller τ values.

It is, perhaps, unsurprising to practicing researchers that as a researcher places more of his or her publications in a top journal that the preexisting publication barriers progressively decrease. There are a number of anecdotally well-accepted mechanisms that likely contribute to this phenomena, being as simple as an increase in research funding resulting from previous high profile publications, the ability to attract the best graduate students, election into a prestigious academy, or simply an editor spending five additional minutes evaluating a new submission by a prominent scientist before making the initial reject or review decision. Nonetheless, it is important that this phenomena be quantified using longitudinal researcher profiles from distinct research fields.

Our first quantitative observation of a decreasing waiting time between publications is consistent with the reasonable assumption that, given a researcher's history of publishing in high-impact journals, his/her next publication is likely to also be high-impact. However, this hypothesis is inconsistent with our second quantitative finding that on average there is a statistically significant decrease in the relative impact of each subsequent publication ($S < 0$) when conditioning on the publication number n. We also observed this imbalance at the individual level, finding more researcher trajectories with statistically significant decreasing trend ($s_i < 0$) than with statistically significant increasing trend ($s_i > 0$), although this asymmetry contributes less to the overall negative S value than the aggregate trend across all scientists. In other words, the decreasing trend is not attributable to individual scientists per se, but rather, is representative of a larger aggregate trend.

Nevertheless, it is important to consider how reputation arising from highly-cited papers may contribute to a detrimental false-positive rate due to the intrinsic noise associated with success outliers [52]. For example, a side-effect of a systematic type-II confirmation-bias error in the identification of high quality research(ers) may induce a 'crowding out' of young and inexperienced scientists. This is not to say that there are not enough opportunities to go around, but that in light of the broad distribution of N_p, it is important to know what role reputation plays in detecting signal from noise. Interestingly, in our analysis of $\langle\tilde{z}(n)\rangle$, we found that the set of researchers with larger N_p cross the zero baseline for a larger n value than the subset with smaller N_p, which was also supported by the positive value of the β_1 coefficient relating s_i and N_p. Together, these two observations indicate that cumulative advantage is functioning properly in the case of researchers with large N_p. It will be important in follow-up research to add more researcher covariates to further test the origin of the non-zero s_i.

So what do our results mean in the context of academic careers? It is difficult to interpret the decreasing impact trend ($S < 0$) as a desirable property of cumulative advantage in science. Since it is likely a researcher consistently publishing in high impact journals is also gaining access to greater resources, it is disappointing that the impact trend is not, at least, stable, if not increasing. But we also have to be careful in over-interpreting this result, since we have shown that impact decreases relative only to the author's average citation impact $\langle z_i \rangle$. Additional explanations for the negative S value and the relative abundance of individual negative s_i values are the difficulty in sustaining high-impact research in the top citation percentile, aging across intrinsic creativity and career life-cycles [19, 53], and aging within knowledge life-cycles reflecting the difficulty in staying at the innovative front of science [54–57].

More generally it is important to discuss the impact of cumulative advantage upon how individual careers evolve and are evaluated. In a system with even a subtle feedback loop, small advantages at an early stage compound over time and can produce stratification at later stages. In the case of academic careers this stratification process can be accelerated by the fact that many careers leave academia at a relatively early stage. Recently that competition increased by the emergence of a 'PhD bubble' characterized by an unreasonably high market valuation of graduate education, resulting in an excessive supply of doctoral degrees. Evidence for this supply-demand imbalance in the US are evident in the number of PhDs awarded relative to tenure-track openings [1–3, 58].

It is important to keep in mind that a small advantage in the early stage can just as easily be due to noise as due to signal. To avoid type I and II errors in career evaluation, extra care should to be taken in evaluating the entire publication portfolio of early stage researchers, not just their high-impact factor publications, to reduce the possibility that early publication success is misinterpreted as a signal of high research potential. On the contrary, it is also important to avoid the scenario in which a scientist is eliminated merely because he/she failed to publish early and consistently in top journals. For early career researchers, especially those with relatively few (and recent) publications, quantitative citation metrics should be used mainly as an initial tool to reduce the candidate pool size [45, 46].

Furthermore, a decreasing barrier to publication in top journals with increasing achievement and reputation (here proxied by n) is important to consider for two reasons. First, one should consider the advantage an early stage researcher has in publishing in top journals via collaboration with a senior research possessing an outstanding track record. Second, the lowering of impact with continued publishing means that, perhaps, higher impact publications by less established researchers are being overlooked by the top journals in favor of lower impact publications by more established ones. In this sense, due to the implicit competition for the select publication slots in highly visible and reputable journals, the current system may be crowding out less established researchers, an inefficiency within the reward system of science suggesting that 'the cream may not always rise to the top.'

It is clear that research careers are multifaceted and complex and in studying them many aspects must be taken into account. Specifically, it is crucial to better understand the role that both social and knowledge networks play in the career growth process, and perhaps one day, understanding how they can be predicted in order to manipulate both research and career success strategies. The most readily available data source for producing insight on careers, and scientific progress in general, is publication metadata. However, this data is shaping how careers are both studied by the science of science community, as well as how academics ad hoc measure their impact and the impact of colleagues. As a result citations are pushed to the forefront, again both in terms of how careers are studied and how researchers view themselves and colleagues. In this regard, we are entering an era where the 'hunters become the hunted.'

3.3 The role of scientometric data science

Moving forward, what can scientometrics offer towards our understanding of careers in science against the backdrop of implicit competition and reward? On one hand, citation data are well-suited for developing testable models of longitudinal productivity and impact dynamics within and across research careers [18, 26]. On the other hand, it can be quite technically challenging (*ex.* overcoming author ambiguity [59, 60]) to extend these analyses beyond productivity and impact and into the social network even if we use the coarse proxy of co-authorship. In Merton's seminal paper 'The Matthew Effect in Science' [24] he outlines the various specific mechanisms by which the reputation premium (Matthew effect) is generated in academic careers. Those mechanisms, however, do not manifest themselves purely in the citation data. Thus it is also important that data outside publication metadata be accessed to shed further light on the role of cumulative advantage. For example, it is important to better understand the embedding of researchers in other advantageous social networks, ones which cannot be captured by co-authorship.

However complex a role cumulative advantage plays in research careers it is a key problem that must be addressed both by the community of researchers studying careers, as well as the gatekeepers of the academic profession, which are often researchers themselves. As with nearly all advances in scientometrics, data must play a critical role and this work represents a small example of how existing data can be exploited to better understand the vast issue of cumulative advantage, and raises the important question as to whether or not the cumulative advantage plays an overall positive roll in the scientific selection process.

Appendix: Data and methods

A.1 Our data-science approach

We defined researcher subsets using several thresholds to account for sources of censoring bias in the data. (a) We removed career profiles with relatively short longevity $L < 5$ years between the first and last publication. (b) We only analyzed profiles with first publication year $y^{j}_{i,0}$ at least a decade after the starting year of the dataset so that we could be reasonably confident that the first publication observed was actually the researchers first publication within the dataset. (c) We conditioned the careers on the number of publications N_p to ensure that there are sufficient statistics to quantify a trend in the citation impact trajectory $\tilde{z}_i(n)$. (d) In our analysis of the citation impact trajectory we only included publications that were published at least 7 years before the TRWOK citation census year Y (corresponding to the data download date which was $Y = 2012$ for the economics journals and $Y = 2009$ for Nat./PNAS/Sci.) to ensure that each publication had a sufficient time to accrue citations which we use as a proxy for research impact. With this time lag, the distribution $P^{j}_{y}(c)$ has time to converge to a log-normal distribution, and the ranking of publications within j is likely to become sufficiently stable that the z value is a robust measure of relative impact.

A.2 Name disambiguation

The 'disambiguation problem' is a major hurdle in the analysis of scientific careers as career profiles may be split or aggregated resulting in inaccurate portraits of productivity and impact. Recent methods have been proposed to solve this problem, ranging from relatively simple name disambiguation methods (as employed here) which provide sufficient accuracy within a reasonably small dataset [35, 61], to more sophisticated network-based solutions that are more appropriate for comprehensive databases like *Thomson Reuters Web of Knowledge (TRWOK)* [60] and comprehensive patent office data (e.g. USPTO) [59].

From *TRWOK* we downloaded annual publication data for 3 high-impact multidisciplinary journals *Nature*, *Proceeding of the National Academy of Sciences USA*, and *Science*; 3 discipline-specific journals *Cell*, the *New England Journal of Medicine (NEJM)*, *Physical Review Letters (PRL)*; 14 top economics journals, *American Economic Review*, *Econometrica*, *Journal of Political Economy*, *Journal of Economic Theory*, *Journal of Econometrics*, *Journal of Financial Economics*, *Journal of Finance*, *Journal of Economic Growth*, *Journal of Economic Perspectives*, *Journal of Economic Literature*, *Quarterly Journal of Economics*, *Review of Economic Studies*, *Review of Financial Studies*, *Review of Economics and Statistics*; and 3 management science journals *Management Science*, *Operations Research*, *Organization Science*. For the natural science journals we restricted our analysis to publications denoted as 'Articles', which excludes reviews, letters to editor, corrections, and other content types. For the economics publications we restricted our analysis to the publication types: 'Articles,' 'Reviews' and 'Proceedings Paper'. Natural science journal data were downloaded and curated in 2009, meaning that the citation counts we analyze do not include citations arriving afterwards. Similarly, the economics and management science journal data were downloaded in 2012.

For a given journal set j we aggregate publications together and create a registry of surname and first/middle-initial pairs {*Surname, FM*} where *FM* can consist of one, two, or three alphabetic characters α, hence $FM = \alpha_1\alpha_2\alpha_3$. For a given journal set, we aggregate and analyze the publications associated with {*Surname, FM*} if it is sufficiently rare in the entire database using the following criteria: if there is only one instance of *FM* for a given {*Surname, FM*} then it is used; however, if there is more than one type of $\alpha_2\alpha_3$ for a given α_1, then this surname and first/middle-initial pairs is omitted from the analysis. For example, we consider *Smith, AM* and *Smith, BM* as not being in conflict, but treat {*Smith, AM*} and {*Smith, A*} as indeterminately distinct authors and so we exclude all profiles with {*Smith*, $A\alpha_2\alpha_3$} from our analysis.

For each {*Surname, FM*} that meets this criteria, we aggregate the corresponding publications together creating a profile which is assigned to author i in a given journal set j. This simple initials-based disambiguation method is well-suited for datasets of similar size to those analyzed here, with demonstrated precision (1-'contamination rate') ranging from 95-97% [35].

We use this method under the assumption that there is no intrinsic bias associated with selecting sufficiently rare {*Surname, FM*} pairs, and hence, the set of 'rare' surname profiles should provide a representative sample from the entire career distribution [61]. Indeed, there are some notable scientists with sufficiently common surnames that are omitted from our analysis, e.g. Stanley HE and Vogelstein B, but we maintain that the number of profiles analyzed is sufficiently large to include a representative proportion of these elite careers comprising the tail of the productivity and citation impact distributions. This assumption appears to be valid, as recent analysis comparing the aggregate h-index distribution $P(h)$ comprising all scientist profiles within the TRWOK dataset with the $P(h)$ comprising only the 'extremely rare' scientist profiles within the TRWOK dataset shows that the distributions are remarkably similar except in the extreme right tail, which is only a finite-size effect due to the difference in dataset sizes [60].

We also note that one source of selection bias arising from the selection of rare surnames is the bias against common Asian and Anglo-Saxon names and in favor of underrepresented nationalities in science. Correcting for this bias is difficult without information on the distribution of surnames in science; however, we assume that its affect is negligible since our simple method was able to extract a significant number of prolific profiles with $5 \leq N_p \leq 20$ within each journal set, providing ample statistics in order to analyze the overall longitudinal trends in citation impact. Future avenues of research in this general direction may benefit from additional covariates, including gender, nationality, and ethnic background, in order to better understand the possible sources of bias.

Additional material

Additional file 1: Supplementary additional figures.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
AMP downloaded, curated, and cleaned the data and performed the statistical analysis. AMP and OP designed research and wrote the manuscript.

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Science PhD Career Preferences: Levels, Changes, and Advisor Encouragement

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Abstract

Even though academic research is often viewed as the preferred career path for PhD trained scientists, most U.S. graduates enter careers in industry, government, or ''alternative careers.'' There has been a growing concern that these career patterns reflect fundamental imbalances between the supply of scientists seeking academic positions and the availability of such positions. However, while government statistics provide insights into realized career transitions, there is little systematic data on scientists' career preferences and thus on the degree to which there is a mismatch between observed career paths and scientists' preferences. Moreover, we lack systematic evidence whether career preferences adjust over the course of the PhD training and to what extent advisors exacerbate imbalances by encouraging their students to pursue academic positions. Based on a national survey of PhD students at tier-one U.S. institutions, we provide insights into the career preferences of junior scientists across the life sciences, physics, and chemistry. We also show that the attractiveness of academic careers decreases significantly over the course of the PhD program, despite the fact that advisors strongly encourage academic careers over non-academic careers. Our data provide an empirical basis for common concerns regarding labor market imbalances. Our results also suggest the need for mechanisms that provide PhD applicants with information that allows them to carefully weigh the costs and benefits of pursuing a PhD, as well as for mechanisms that complement the job market advice advisors give to their current students.

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Introduction

Policy makers, scholars, and members of the science community are concerned that PhD-trained scientists face a shortage in available faculty positions, which are assumed to be the most desired careers in many fields [1–4]. Consistent with that concern, many scientists enter careers outside of academia. For example, a recent analysis of data from the 2006 Survey of Earned Doctorates conducted by the National Science Foundation shows that 5–6 years after graduation, only about 14% of PhDs in the biological sciences held tenure-track positions, compared to 21% of physicists and 23% of chemistry PhDs. Larger numbers of individuals hold non-tenure track academic positions, especially in the biological sciences (34%) and in physics (20%). Industry employs about 23% of biological scientists, 34% of physicists, and 46% of chemists 5–6 years after they had obtained their PhD [5]. Unfortunately, these aggregate numbers reflect the joint effects of both supply and demand conditions. There is little recent data on scientists' underlying career preferences and thus on the degree to which there is a mismatch between scientists' desired careers and the career opportunities actually available to them [6]. In addition, it has been suggested that career preferences may change over the course of graduate training, yet empirical evidence on such changes is limited [6,7]. Finally, while it is sometimes argued that advisors exacerbate labor market imbalances by encouraging students to pursue faculty careers [5,8], there is no systematic data on the degree to which advisors indeed encourage faculty versus alternative career paths. Empirical insights regarding these issues are of interest to policy makers who invest significant funds in graduate education [9], as well as to academic administrators and advisors who design graduate courses and training experiences [10,11]. Perhaps most importantly, such insights may also help junior scientists in thinking about their future career paths.

In this paper we draw on novel survey data to provide unique insights into PhD students' career preferences, changes in preferences over the course of the PhD program, and faculty advisors' encouragement of specific career paths. In conjunction with existing data on the realities of labor market opportunities, our results speak to common concerns regarding labor market imbalances. At the same time, our data suggest the need to consider important differences across fields.

Results

We conducted a large-scale survey among PhD students at 39 tier-one U.S. research universities in the spring of 2010. Our sample includes 4,109 PhD students in the life sciences (59%), chemistry (18%), and physics (23%). Table S1 shows a complete listing of universities included in the sample and Table S2 provides a listing of subfields. Thirty-six percent of respondents indicated that they were on the job market at the time of the survey or were planning to be on the job market within the next year, and 26% of respondents had not yet completed their qualifying exam or similar milestones. The average time in the program was 3.7 years. The Materials and Methods section below provides a detailed discussion of the survey. Table S3 shows summary statistics.

Our empirical analysis proceeds as follows. First, we describe the measures of career preferences and provide insights into the levels of students' preferences for careers in academia (faculty research and faculty teaching), industry (established firms and startups), as well as government R&D and "other" careers. We then examine changes over time by comparing preferences across cohorts of students and by comparing current and retrospective measures within a given student. Third, we provide data on the degree to which students perceive that their advisors or departments encourage or discourage particular careers. Finally, we provide detailed insights into respondents' interests in particular work activities such as basic research, applied research, or technology commercialization.

Levels of career preferences

Our primary interest is in respondents' career preferences, i.e., which career paths they find attractive regardless of job market conditions. Thus, we asked respondents to ignore job availability and rate how attractive they find each of the following careers: (a) a faculty career with an emphasis on teaching; (b) a faculty career with an emphasis on research or development; (c) a government job with an emphasis on research or development; (d) a job in an established firm with an emphasis on research or development; (e) a job in a startup with an emphasis on research or development; and (f) other career. Since additional postdoctoral training is very common in some fields [12,13], we explicitly asked respondents to state their career preferences with respect to employment after graduation and any potential postdocs. Table S4 provides detailed data on the distribution of responses in each response category, ranging from 1 ("extremely unattractive") to 5 ("extremely attractive"). Figure 1 shows the percentage of respondents rating a particular career as extremely attractive (score of 5) by broadly defined field. Figure 1 shows results separately for students in early stages of the PhD program and for those who were on the job market in the year of the survey or were planning to look for jobs within the next year.

Consistent with field differences in actual career patterns [5], we observe considerable differences in career preferences across fields. Across all cohorts, students in the life sciences and physics most often rate a faculty career with an emphasis on research as extremely attractive (34% and 38% of students, respectively), followed by teaching careers and R&D positions in government. Among chemistry PhD students, an R&D career in an established firm is most often considered extremely attractive (27%), followed by R&D careers in government (21%). Figure 1 also shows that some respondents find "other" career extremely attractive. We asked respondents to specify which particular career they were thinking of, and the most commonly mentioned careers include science communication/writer, science policy, non-university teaching, working for a non-profit/NGO, and consulting.

Figure 1 shows the share of students who find a particular career extremely attractive in an absolute sense. To assess the attractiveness of the various career paths *relative to each other*, we coded a new set of variables, indicating which of the six career options received the highest attractiveness rating. Since respondents may judge multiple careers as similarly attractive, this measure also includes ties. Figure 2 shows that a faculty position with focus on research is among the most attractive careers for over 50% of life scientists and physicists, while a research position in an established firm is among the most attractive options for over 50% of chemists.

Changes over time

In addition to important differences across fields, Figure 1 also shows significant differences across cohorts of students within a given field. For example, the share of life sciences students finding a faculty research career extremely attractive is significantly lower in the late stage versus the early stage of the PhD program (33% vs. 39%, $p<0.01$). Similarly, the share of life sciences students finding a faculty teaching career extremely attractive declines from 25% to 21% ($p<0.05$). In chemistry, we observe a significant decrease in the share of students finding teaching careers extremely attractive (21% vs. 16%, $p<0.01$) and a sharp increase in the attractiveness of careers in industry (37% vs. 23%, $p<0.01$). There is some evidence that the attractiveness of startup careers increases in all three fields, although these changes are not statistically significant at conventional levels of confidence.

Decreases in the attractiveness of faculty careers and concomitant increases in the attractiveness of nonacademic careers lead to even sharper shifts in the share of students finding a particular career *most* attractive compared to all other careers (the measure used in Figure 2). In particular, the share of students finding a faculty research career most attractive drops in all three fields, from 57% for the early cohort to 50% for the late cohort in the life sciences, from 45% to 32% in chemistry, and from 60% to 53% in physics.

The detailed data presented in Table S4 show changes not only in the share of students who find particular careers extremely attractive, but also in the share of students who find particular careers unattractive. Most notably, we find that the share of students who find a faculty research career "unattractive" or "extremely unattractive" increases from 11% to 21% ($p<0.01$) in the life sciences, 22% to 38% ($p<0.01$) in chemistry, and 7% to 14% ($p<0.05$) in physics.

One interpretation of these differences across cohorts is that students' preferences change over the course of graduate training. For example, students may enter graduate school with overly positive views of the faculty career and may change their expectations upon experiencing academic life first-hand [7,14–16]. Similarly, students may learn about career paths outside of academia and may come to appreciate their advantages [7,17]. Moreover, even though our question asked students to ignore job availability, the responses of some later-stage students may reflect that they realized over time that they are not competitive for scarce academic jobs and thus ceased to "want" them.

In addition to such changes within a given individual, however, the differences across cohorts reported in Figure 1 may also reflect "cohort effects" [18]. More specifically, the students who were in the late stage of the PhD at the time of the survey may have been different from those in the early stage even when they initially entered the PhD program, e.g., due to different labor market conditions at the time of enrollment in the PhD. To more clearly assess changes over time for a given individual and to eliminate cohort effects, we asked respondents in the late stage of the PhD in what year they started their program and to recall how certain they were at that time to pursue the various career options. We examined changes in career preferences within a given individual by comparing which career received the highest rating at the time of the survey versus at the time of enrollment in the PhD program. Figure 3 visualizes these changes over time. For example, Figure 3 shows that 18.3% of respondents in the life sciences rated a faculty research career highest when starting their PhD program, but did not rate this career highest at the time of the survey. Thus, relative to other careers, the faculty research career became less attractive for 18.3% of life sciences PhD students. At the same time, 8.7% of them rated the faculty research career as most attractive at the

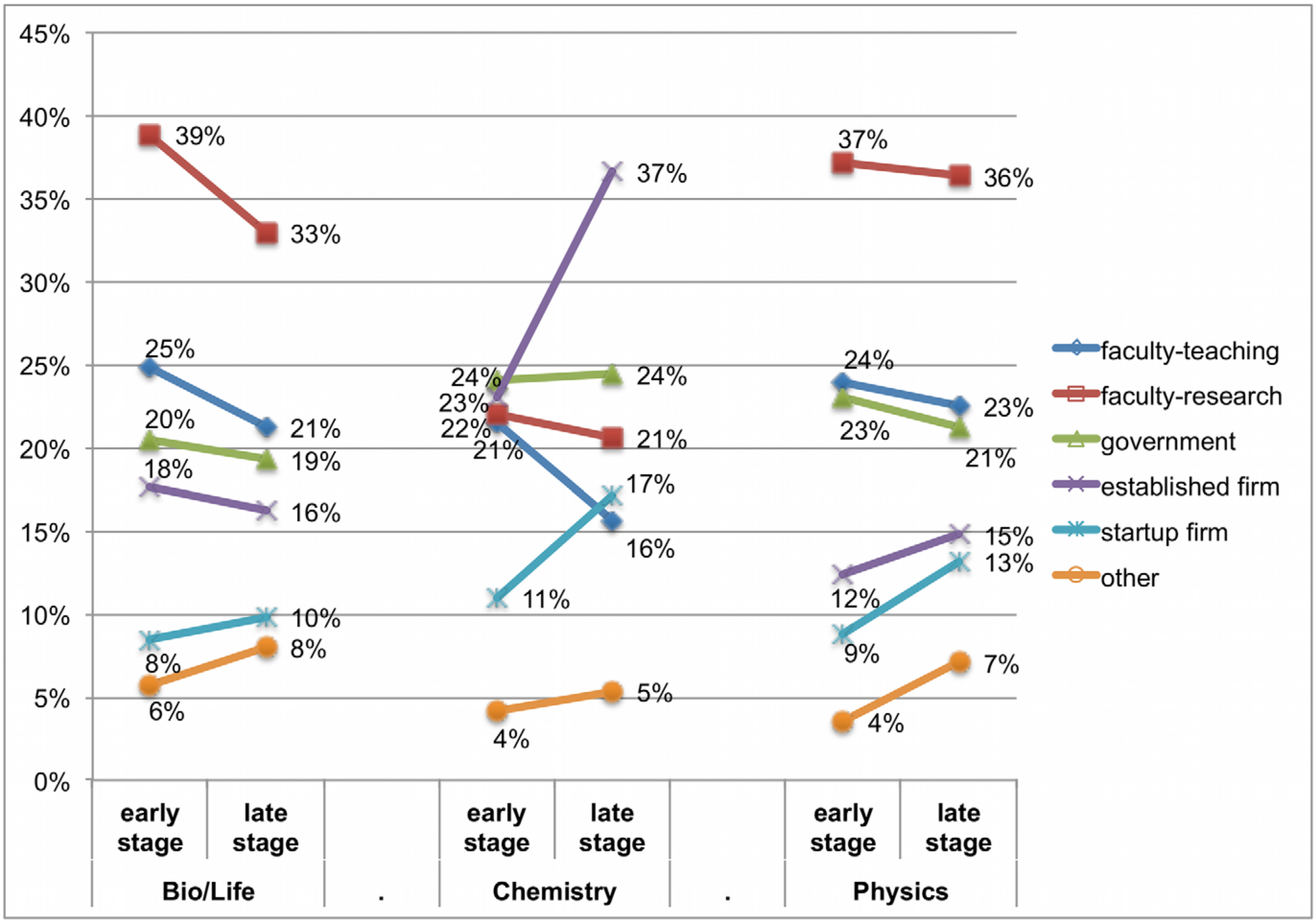

Figure 1. Students judging a career "extremely attractive" by field and stage in program. Respondents rated the attractiveness of each career on a 5-point scale (and were instructed to ignore job availability). The scale anchors ranged from 1 (extremely unattractive) to 3 (neither attractive nor unattractive) to 5 (extremely attractive). Figure 1 shows the share of respondents who gave a rating of 5 ("extremely attractive") to a particular career. Data are shown separately for respondents in the early stages of the PhD program (prior to completion of qualifying exams or similar milestones) and in the late stages of the PhD program (looking for a job at the time of the survey or planning to do so within the next year).
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time of the survey, even though they had not done so at the time of joining the PhD program; for these respondents, the faculty research career became relatively more attractive over time. Taken together, these numbers suggest an overall decline in the relative attractiveness of the faculty research career among life sciences PhD students: the share of respondents who rated this career highest declined by 9.6 (= 18.3–8.7) percentage points. This drop is even more pronounced in physics, where the share of respondents who rated the faculty research career highest dropped by 12.8 percentage points. In chemistry, the share decreases by 5 percentage points.

If academic research became relatively less attractive over time, which careers became relatively more attractive? Figure 3 shows that many students at the end of the PhD program consider an R&D career in government the most attractive, even though they had not done so at the beginning of the PhD. More specifically, the share of respondents who rate this career highest increased by 10.9 percentage points in the life sciences, 13 percentage points in chemistry, and 5.1 percentage points in physics. While our survey itself does not provide insights into the underlying drivers of this change, informal interviews with PhD students suggest that perceived high levels of job security and access to funding, as well as the recognition that government labs provide opportunities to do quite "academic" research may play an important role. Note, however, that changes in the attractiveness of government jobs emerge only in the within-individual analysis; we did not find significant differences between early and late cohorts (see Figure 1).

Despite the decline in the attractiveness of faculty careers over time, our data show that the faculty research career remains extremely attractive to a large share of graduating students in the life sciences and in physics (see Figure 1). As detailed in the introduction, however, NSF data show that the share of graduates who are actually able to obtain tenure track faculty positions is significantly smaller [5]. Thus, our data on career preferences complement existing data on available positions and provide empirical support for growing concerns about imbalances in the scientific labor market [1,3,16].

Advisor encouragement

The strong interest in faculty research positions despite the low availability of such positions raises the question to what extent advisors and departments further encourage students to pursue academic positions and to what extent they are supportive of careers in other sectors. Despite the common belief that advisors have a strong interest in encouraging students to enter academic careers [5,8,19], systematic evidence is lacking. We asked

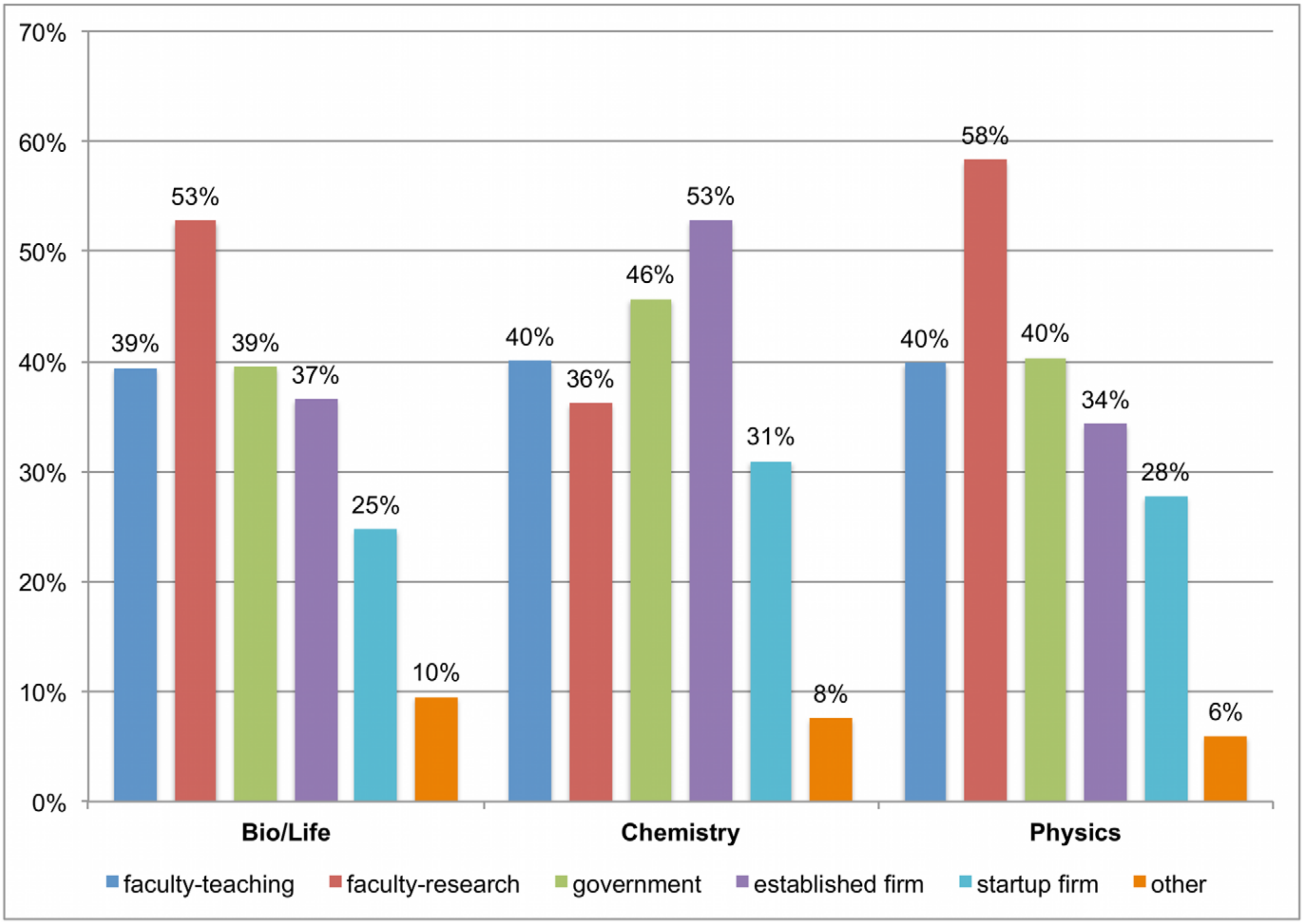

Figure 2. Most attractive career path (full sample; ties possible). Respondents rated the attractiveness of each career path on a 5-point scale. Figure 2 shows the share of respondents who gave their highest rating to a particular career. For example, 53% of life sciences PhD students gave their highest attractiveness rating to the faculty research career. Since careers were rated independently, careers can be tied (i.e., receive the same attractiveness score).
doi:10.1371/journal.pone.0036307.g002

respondents to what extent they felt that PhD students in their lab/department are encouraged or discouraged to pursue the various careers, using a scale ranging from 1 (strongly discouraged) to 3 (neither discouraged nor encouraged) to 5 (strongly encouraged). The results are plotted in Figure 4; the source data are shown in Table S5. Figure 4 shows that the faculty research career is indeed by far the most often ''strongly encouraged'' career. A small number of students feel that certain other careers are explicitly discouraged, mostly teaching careers and careers in industry. It is notable that encouragement for faculty careers and discouragement for industry careers are especially pronounced in the life sciences, where the share of graduates obtaining tenure track faculty positions is smallest and where much of the discussion around labor market imbalances takes place [5]. Even in chemistry, where industry careers are very common and where students express a strong interest in industry careers, students feel that research careers in academia are much more strongly encouraged.

Figure 4 also shows that a considerable share of students feels that non-academic careers are neither encouraged nor discouraged. One possible interpretation is that these careers are discussed between students and their advisors and that the latter explicitly take a ''neutral'' stance with respect to these careers. Alternatively, these career options may not be very salient in student-advisor discussions, and the neutral ratings in Figure 4 may reflect a lack of guidance and information regarding these careers rather than an explicit neutral position. Further research on the depth and scope of advisor-student discussions regarding career trajectories is needed to disentangle these two mechanisms.

Interest in different kinds of work activities

While our focus is on students' preferences for different types of careers and employment sectors, we also collected data specifically on their interest in different types of work. In particular, we asked respondents how interesting they would find each of 5 different types of work in the future, including ''research that contributes fundamental insights or theories (basic research);'' ''research that creates knowledge to solve practical problems (applied research);'' ''using knowledge to develop materials, devices, or software (development);'' ''commercializing research results into products or services;'' ''management/administration;'' and ''teaching.'' Figure 5 shows the distribution of ratings, ranging from ''extremely uninteresting'' to ''extremely interesting'' (source data in Table S6). In the life sciences and in chemistry, the largest share of ''extremely interesting'' ratings is given to applied research. Among physicists, basic research is most often rated as ''extremely interesting.'' Teaching is rated as ''extremely interesting'' by

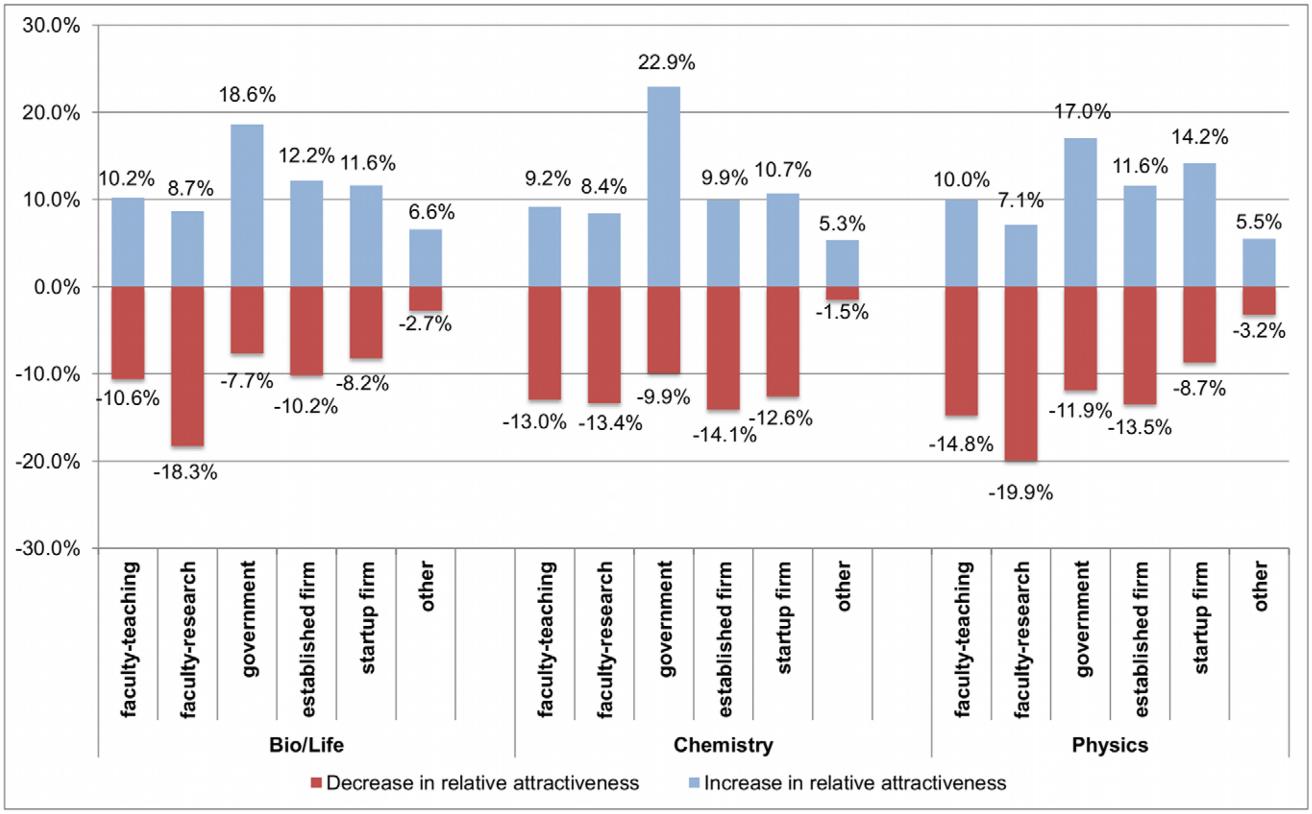

Figure 3. Change in the relative attractiveness of careers over time (respondents in the late stage of the PhD). Respondents were asked how certain they were at the time of beginning the PhD program to pursue each career. Similarly, respondents were asked how attractive they found each career at the time of the survey. For each of the two points in time, we coded which career received the highest rating (ties possible). Positive numbers in Figure 3 show the share of respondents who gave the highest rating to a particular career at the time of the survey but not when starting the PhD (i.e., the relative attractiveness of that particular career increased). Negative numbers show the share of respondents who gave the highest rating when starting the PhD but not at the time of the survey (i.e., the relative attractiveness decreased). For example, the relative attractiveness of a faculty research career increased over the course of the program for 8.7% of life sciences PhD students but decreased for 18.3% of life sciences PhD students. The net effect is a decrease in the share of students who rate the faculty career as most attractive by 9.6 percentage points.
doi:10.1371/journal.pone.0036307.g003

approximately 20% of respondents, with only small differences across fields.

In light of a growing interest in translational research and academic entrepreneurship in both the scholarly and the policy communities [20–22], it is notable that many students in the life sciences and in chemistry have a strong interest in research that solves concrete problems. At the same time, the share of scientists who would be interested in getting actively involved in technology commercialization is significantly smaller, and many respondents find commercialization uninteresting or even extremely uninteresting. Future research is needed to examine how the distribution of work interests matches with the needs of prospective employers in the various sectors of the economy.

Discussion

Our data show that a faculty research career is the career path most often considered "extremely attractive" and ranks among the most desirable careers for over 50% of life scientists and physicists. Given that the number of faculty positions is much smaller [5], these findings support the concern that the supply of science PhDs interested in faculty research positions significantly exceeds the number of available positions in these fields. At the same time, the majority of chemistry students as well as significant shares of students in the life sciences and in physics prefer careers outside of academia, regardless of job availability. Academic administrators and advisors should consider such heterogeneity in career preferences when designing graduate curricula, ensuring that students have opportunities to acquire the skills and knowledge required to perform in non-academic careers that may not only be more readily available but are also quite attractive to students themselves [6,10]. Similarly, the public discussion may benefit from recognizing that labor market experiences may be quite different depending on which particular career a junior scientist seeks to pursue.

Second, respondents across all three major fields feel that their advisors and departments strongly encourage academic research careers while being less encouraging of other career paths. Such strong encouragement of academic careers may be dysfunctional if it exacerbates labor market imbalances or creates stress for students who feel that their career aspirations do not live up to the expectations of their advisors. In the context of prior findings that students feel well-informed about the characteristics of academic careers but less so about careers outside of academia [17], our results suggest that PhD programs should more actively provide information and training experiences that allow students to learn about a broader range of career options, including those that are currently less encouraged. Richer information and a more neutral

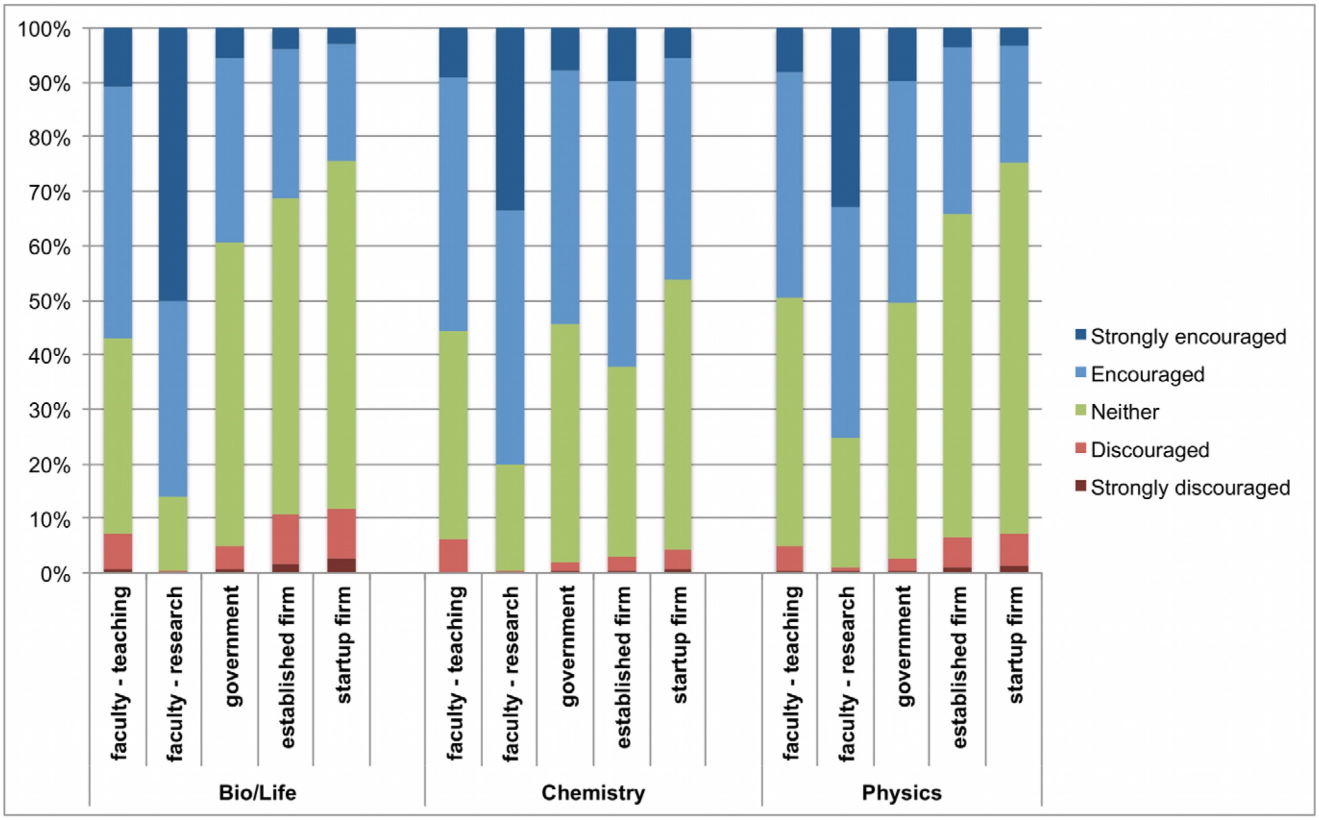

Figure 4. Share of students reporting that particular careers are encouraged/discouraged in their lab or department. Respondents rated on a 5-point scale the degree to which PhDs in their lab/department are encouraged or discouraged to pursue each career. Figure 4 shows the share of respondents choosing each response category. Raw data for this figure are shown in Table S5.
doi:10.1371/journal.pone.0036307.g004

stance by advisors and departments will likely improve career decision-making and has the potential to simultaneously improve labor market imbalances as well as future career satisfaction [23,24]. Advisors' apparent emphasis on encouraging academic careers does not necessarily reflect an intentional bias, however. Rather, it may reflect that advisors themselves chose an academic career and have less experience with other career options. Thus, administrators, policy makers, and professional associations may have to complement the career guidance students' advisors and departments provide.

Third, our data suggest that students' interest in academic research declines over the course of the PhD training, while other careers become relatively more attractive. Future research is needed to examine the underlying sources of such changes and potential implications for science education and scientific labor markets. The observed changes in career preferences may be beneficial if they reflect that students acquire more information about career options, potentially leading to better career decisions. However, a declining interest in a faculty research career may also imply a greater divergence between students' interests on the one hand, and the academic orientation of traditional PhD curricula as well as advisor expectations on the other [8]. To the extent that the strong interest in a faculty career at the beginning of the PhD reflects a lack of information about the challenges and job prospects of faculty careers, providing such information to applicants *prior* to enrollment in the PhD may allow them to more accurately evaluate the costs and benefits of pursuing a PhD. Of course, stronger (self−)selection prior to enrollment may reduce the number of graduate students available to work in academic labs, potentially requiring changes to how scientific labor is organized in academic research [3,4].

This study is not without limitations. First, our sample is drawn from larger PhD programs at tier- one institutions. While the institutions in our sample account for a large share of the total production of U.S.-trained PhDs, our results may not generalize to students in smaller or lower-tier programs. Second, even though we explicitly asked students to ignore job availability, the weak job market may have led some respondents to understate the attractiveness of hard to get positions. While we believe that any such effect is small, it would imply that scientists' "true" preferences for faculty careers are even stronger than shown in the data, suggesting an even larger mismatch between career preferences and career opportunities.

Materials and Methods

Ethics statement

This research has been approved by the Georgia Institute of Technology's Institutional Review Board. Given the sensitive nature of the data, all respondents were ensured confidentiality. Respondents read a consent form prior to taking the survey and agreed by clicking on a link to proceed with the web survey. The data shown in this study have been anonymized.

Data collection

We identified 39 tier-one U.S. research universities with doctoral programs in science and engineering fields by consulting the National Science Foundation's reports on earned doctorates

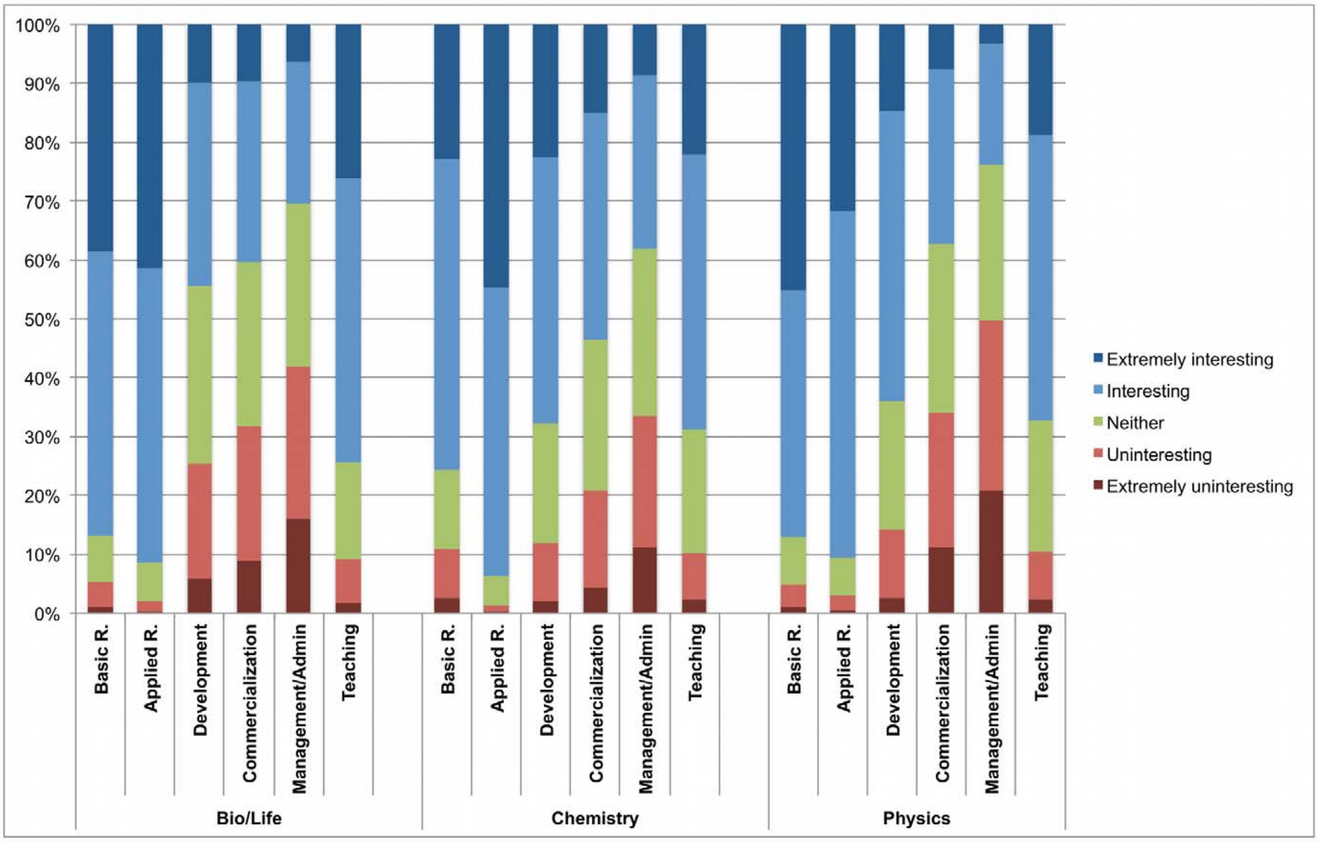

Figure 5. Share of students finding particular work activities interesting/uninteresting. Respondents indicated how interesting they would find each of six kinds of work when thinking about the future. Figure 5 shows the share of respondents choosing each response category. Raw data for this figure are shown in Table S6.
doi:10.1371/journal.pone.0036307.g005

[25]. Our selection of universities was based primarily on program size while also ensuring variation in private/public status and geographic region. The 39 universities in our sample produced roughly 40% of the graduating PhDs in S&E fields in 2009 [25]. Table S1 shows the number of cases in each of the 39 universities. While our results should be representative of students at larger tier-one universities, they do not necessarily generalize to graduate students at smaller and lower-tier institutions.

We collected roughly 30,000 individual names and email addresses from listings provided on our target departments' websites. We invited these individuals to participate in the survey using a four-contact strategy (one invitation, three reminders). All surveys were conducted online, using the software suite Qualtrics (www.qualtrics.com). Adjusting for 6.3% undeliverable emails, the direct survey approach achieved a response rate of 30%. This response rate reflects respondents who actually finished the survey, i.e., who saw all pages of the survey and pressed "next" on the final page. We dropped respondents who started the survey but did not finish it. Item non-response among those who finished was low (less than 2%) and we imputed missing items using multiple regression. Further details on the survey strategy are provided in [26].

When individual contact information was not available, we used department administrators as a second channel to approach respondents. In those cases, we emailed administrators with the request to forward a survey link to their graduate students and our research assistants additionally called administrators on the telephone to encourage their cooperation. Overall, 88% of our responses were obtained directly from respondents and 12% were obtained through administrators.

The initial survey sample is very broad and this study focuses on the sub-sample of 4,109 PhD students in the life sciences (59%), chemistry (17.7%), and physics (23.2%). According to data from the Survey of Earned Doctorates, the comparable shares of PhD degrees granted in the US in 2009 are 68% for the life sciences, 18% for chemistry, and 14% for physics [25]. We conducted all analyses separately by field such that the oversampling of physics PhDs does not affect our results. Table S2 shows the number of cases in each subfield.

Measures

Current career preferences. We asked respondents: *Putting job availability aside, how attractive do you personally find each of the following careers?*

- *University faculty with an emphasis on teaching*
- *University faculty with an emphasis on research or development*
- *Government job with an emphasis on research or development*
- *Job in established firm with an emphasis on research or development*
- *Job in startup/entrepreneurial firm with an emphasis on research or development*
- *Other (please specify):*

Respondents rated each career on a 5-point scale ranging from 1 (extremely unattractive) to 3 (neither attractive nor unattractive) to 5 (extremely attractive). This item was placed in a section of the questionnaire beginning with "The following questions refer to future employment after graduation and any potential postdocs."

Stage in the PhD program. We asked respondents: *What stage are you in the PhD program? Please check all that apply.*

I. *have not yet passed my qualifying exam*
II. *am working on my dissertation research*
III. *am working on non-dissertation research (e.g., as research assistant)*
IV. *intend to begin actively looking for a job or post-doc position within the next year*
V. *am actively looking for a job or a post-doc position*

We coded the following three dummy variables: STAGE_EARLY = 1 if a respondent checked the first option. STAGE_LATE = 1 if respondent checked one of the last two options. STAGE_MIDDLE otherwise.

Career preferences at the start of the PhD program. We asked respondents: *Thinking back to when you began your PhD program in [year], how certain were you at that time that you wanted to pursue the following careers?*

- *University faculty with an emphasis on teaching*
- *University faculty with an emphasis on research or development*
- *Government job with an emphasis on research or development*
- *Job in established firm with an emphasis on research or development*
- *Job in startup/entrepreneurial firm with an emphasis on research or development*
- *Other (please specify):*

Respondents rated each option on a 5-point scale ranging from 1 (certain not to pursue) to 3 (uncertain whether to pursue) to 5 (certain to pursue).

Interest in research and non-research work activities. We asked respondents: *When thinking about the future, how interesting would you find the following kinds of work?*

- *Research that contributes fundamental insights or theories (basic research)*
- *Research that creates knowledge to solve practical problems (applied research)*
- *Using knowledge to develop materials, devices, or software (development)*
- *Commercializing research results into products or services*
- *Management/Administration*
- *Teaching or training others*

Respondents rated each item on a 5-point scale ranging from 1 (extremely uninteresting) to 3 (neither interesting nor uninteresting) to 5 (extremely interesting).

Degree to which careers are encouraged/discouraged in lab/department. We asked respondents: *In your lab/department, to what extent are PhDs encouraged or discouraged to pursue the following careers?*

- *University faculty with an emphasis on teaching*
- *University faculty with an emphasis on research or development*
- *Government job with an emphasis on research or development*
- *Job in established firm with an emphasis on research or development*
- *Job in startup/entrepreneurial firm with an emphasis on research or development*

Respondents rated each item on a 5-point scale ranging from 1 (strongly discouraged) to 3 (neither encouraged nor discouraged) to 5 (strongly encouraged).

Subfield. We asked respondents: *Which of the following best describes your general field and area of specialization?* Respondents selected one of the options shown in Table S2. Given the framing of the question, we assume that respondents in interdisciplinary programs chose the field that best reflects their current work.

Measurement issues

In line with prior research on S&E career preferences [11,17,27], we rely on direct measures of preferences by asking the decision makers. An alternative approach to measuring preferences is to infer preferences from observed choices or outcomes [28–30]. While both measurement approaches have their advantages, the latter "revealed preferences" approach assumes that individuals do in fact have a choice between the relevant alternatives. In our particular context, inferring career preferences from actual career transitions could underestimate scientists' preferences for academic careers if academic positions are in limited supply and some scientists who would prefer an academic position are forced to take positions in other sectors. We sought to further reduce the influence of labor market conditions by asking respondents explicitly to ignore job availability. Thus, we seek to understand which careers junior scientists find attractive rather than which careers they think they will have to pursue due to job market conditions. This aspect is particularly important given potential imbalances in scientific labor markets. While our approach may not completely eliminate the influence of job market conditions, it provides a clearer assessment of preferences than either realized career transitions or self-reports that do not ask respondents to ignore job market conditions.

A general concern with self-reported measures of preferences for careers or work activities is that respondents may overstate preferences that seem socially desirable (e.g., research in academia) and give artificially low scores to preferences that may seem less socially desirable [31]. To mitigate this concern, we stated clearly in the survey invitation that responses would be kept strictly confidential.

One of our analyses of changes over time relies on retrospective measures of career preferences at the start of the PhD program. While retrospective questions can be useful if no real-time measure is available, respondents may not always accurately report past behaviors and intentions. It has been suggested, for example, that respondents sometimes assume unrealistic high degrees of stability, resulting in retrospective reports that are more similar to current behaviors and intentions than is warranted [32,33]. Similarly, respondents may be motivated to report past intentions that are similar to current intentions or outcomes in order to appear "consistent." While we are not able to explicitly assess the potential for such biases in our data, both effects would suggest that our estimates of within-individual changes in career preferences (Figure 3) are conservative. Future research assessing changes in career preferences using multiple real-time measurements is needed to complement our analysis.

Finally, in interpreting the results regarding advisor encouragement, it has to be kept in mind that our measures reflect students' perceptions of the degree to which certain careers are encouraged/discouraged in their lab or department. While these perceptions should have the most direct impact on junior scientists' career decisions, future research should also examine objective measures of advisor encouragement.

Supporting Information

Table S1 Universities included in sample and number of cases in each.
(DOCX)

Table S2 Subfields and number of cases in each.
(DOCX)

Table S3 Summary statistics, by field.
(DOCX)

Table S4 Detailed distribution of current career preferences, by stage in program.
(DOCX)

Table S5 Data for Figure 4 (share of students reporting that particular careers are encouraged/discouraged in their lab or department).
(DOCX)

Table S6 Data for Figure 5 (share of students finding particular work activities interesting/uninteresting).
(DOCX)

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Author Contributions

Conceived and designed the experiments: MR HS. Performed the experiments: MR HS. Analyzed the data: HS. Wrote the paper: MR HS.

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Women of Color in Academe: Living with Multiple Marginality

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Women of Color in Academe

Living with Multiple Marginality

Introduction

I recall a personal example of how multiple social identities may shape one's opportunities in higher education. As a woman of color from a "no collar" class (I come from a farm labor background), when first exploring graduate school options I was discouraged from applying to a master's level program in business by an admissions officer. The admissions officer stated that I would not fit. I was a woman, a minority, a single parent, I had a background in the public sector, and I had some but not enough math background. This would make it nearly impossible for me to succeed as others in the program fit another and opposite profile. Although all of this may be true, it did not occur to the admissions officer that this might not be an appropriate state of affairs for student enrollment in the program. It was merely accepted as the way things are and should remain. I remember being struck by the many ways I could be defined as not "fitting" and, therefore, not encouraged and, more than likely, not admitted. I was so easily "defined out" rather than "defined in."

I am now a faculty member at a major research university. My current work focuses on the experiences of faculty of color in higher education. While pursuing this work, I have had many opportunities to interview, converse with, and read about the lives of other faculty women of color. Many continue to speak, although in different ways, about the experi-

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ence of multiple marginality and being defined out. The following quotations from the literature give insight into the lives of faculty women of color, including my own.

Lived Contradiction

> I am struck by my lived contradiction: To be a professor is to be an *anglo*; to be a *latina* is not to be an *anglo*. So how can I be both a Latina and a professor? To be a Latina professor, I conclude, means to be unlike *and* like me. Que locura! What madness! . . . As Latina professors, we are newcomers to a world defined and controlled by discourses that do not address our realities, that do not affirm our intellectual contributions, that do not seriously examine our worlds. Can I be both Latina and professor without compromise? (Ana M. Martinez Aleman in Padilla & Chavez, 1995, pp. 74–75)

Ambiguous Empowerment

> Readers who have listened to any group of professional women talk about their work experiences will likely find these stories familiar. Like other successful women who work in male and white-dominated professions, women superintendents have much to say about the way they managed to get into such positions despite the anomaly of their gender or race, how they developed confidence in their competence and authority, and what they have accomplished by exercising their professional power. They also talk about various forms of gender and race inequality that structure the profession and how they respond to discriminatory treatment…I study these familiar stories in order to understand how professional women make sense of their—their ambiguous empowerment—in the context of contemporary American culture. (Chase, 1995, p. x)

The narrative data presented here portray the lives of faculty women of color as filled with lived contradictions and ambiguous empowerment. Chase's (1995) "ambiguous empowerment" based on the lives of women school superintendents also applies to the experiences of faculty women of color. Although faculty women of color have obtained academic positions, even when tenured they often confront situations that limit their authority and, as they address these situations, drain their energy. For example, in an interview[1] a woman of color who is a full professor and chair of her department observes:

> I'm the department chair, . . . and I meet with a lot of people who don't know me—you know, prospective students and their parents. And I know that their first reaction to me is that I'm an Asian American woman, not that I'm a scientist or that I'm competent.

Statements by faculty women of color typically relay such observations. Unfortunately, the lives of faculty women of color are often invisible, hidden within studies that look at the experiences of women faculty and within studies that examine the lives of faculty of color. Women of color fit both categories, experience multiple marginality, and their stories are often masked within these contexts.[2] This article seeks to redress such shortcomings by presenting experiences expressed by faculty women of color in interviews conducted by the author and in statements published in the higher education literature. At times I include personal observations. I conclude with a set of recommendations to increase the positive experiences for faculty women of color.

How Do Proportions Count?

To begin, it is informative to discuss the importance and implications of representation or lack of representation within organizations. Kanter's theory of proportions (1977) first made me aware of the potential effects of marginality on social interactions and mobility in a corporate setting. Briefly, Kanter describes the effect of being a "token." She states that the numerical distribution of men and women in the upper reaches of the corporation provide different interaction contexts for those in the majority versus those in the minority (p. 206). For example, women in the minority (in very small proportion) inhabit a context characterized by the following:

- Being more visible and on display
- Feeling more pressure to conform, to make fewer mistakes
- Becoming socially invisible, not to stand out
- Finding it harder to gain credibility
- Being more isolated and peripheral
- Being more likely to be excluded from informal peer networks, having limited sources of power through alliances
- Having fewer opportunities to be sponsored
- Facing misperceptions of their identity and role in the organization
- Being stereotyped
- Facing more personal stress

Those in the majority (in very high proportion) face the opposite social context. They are seen as one of the group, preferred for sponsorship by others inhabiting higher level positions (pp. 248–249).

Although Kanter's work articulates the social situation for "tokens" quite well, she primarily speaks to the situation of White women in an organizational setting. Kanter's argument suggests that those who differ from the norm within the corporate hierarchy encounter a cycle of cumulative disadvantage, whereas those who fit the norm experience a cycle of cumulative advantage. Her theories imply that the more ways in which one differs from the "norm," the more social interactions will be affected within multiple contexts. Situations in which a woman of color might experience marginality are multiplied depending on her marginal status within various contexts. Often it is difficult to tell whether race or gender stereotyping is operating. When asked if she experienced any barriers, one woman of color in academe, quoted in Hune (1998), responded: "The answer is yes. I think for me personally, it's hard to know if it's because I am a woman or because I am Asian, or both" (p. 11). In a conversation with me, another faculty member stated: "Dealing with the senior, [mostly white] males in my department has been a huge challenge. . . . I don't know if they tend to discount my contributions because I'm new, female, Latina, young, or what. Perhaps a combination of all of the above." Rains (1999) calls attention to the complexities that daily pervade the experiences of many women of color in the academy (p. 152).

Cho (1996) sheds light on the complexities of defining parity. Her work describes bias suffered by Asian Pacific Americans in the academic workplace even though the perception is that they are well represented and, therefore, successful. She contends the following: (1) numbers showing over-parity in some fields or disciplines mask related under-parity in other fields; (2) over-parity status at the entry level does not mean over-parity status higher up on the promotion ladder; and (3) inferences drawn from an aggregated over-parity status serve to make invisible the varied needs of a heterogeneous population (p. 34). Cho's work made me realize that drawing a statistical picture of numerical "inclusion" without reflecting on the context of that inclusion and "quality of life" factors paints an incomplete portrait.

Representation and the Creation of Campus Climate

Studies by Harvey (1991) and Spann (1990) further illuminate the importance and complexity of representation in the development of the campus climates within which faculty women of color work. According to Harvey, "campus climate" is a "term used to describe the culture, habits, decisions, practices, and policies that make up campus life. The degree to which the climate is hospitable determines the 'comfort factor' for African Americans and other nonwhite persons on campus" (p. 128). In defining the chilly climate within an academic setting, Spann gives voice to discussions by her study respondents (referred to as panelists):

> Panelists defined climate as the quality of respect and support accorded to women and minorities on individual campuses and in individual depart-

> ments. They believed that climates were created by institutions and could be measured in specific ways, . . . by the number of women and minority faculty members at junior and senior levels, . . . by the social distance between majority and minority group faculty and administrators, . . . by the equitability of work assignments. (p. 1)

Spann's study implies that nontraditional faculty representation within different locations (i.e. junior and senior faculty status as well as administrative positions) in the organization determines, in large part, what her respondents describe as campus climate. Providing support for the impact of social distance argument, Etzkowitz, Kemelgor, and Uzzi (2000) stress that the existence of a "critical mass" (i.e., at least 15% of women in an organization) to address tokenism will not fully address the situation of the minority in an organization. They state that "the precise number is less important than the nature of the response the new minority receives from the majority" (p.107).

Representation and Distribution: Demographic Data

The Chronicle of Higher Education Almanac (2001) reports that the total of full-time faculty members, including instructor and lecturer, is 568,719, of which 204,794 (36%) are women. Of the total women, 29,546 (14%) are women of color. Table 1 shows the underrepresentation of women of color in the professoriate by rank and racial/ethnic breakdown.

Similar patterns are reported for the Instructor and Lecturer categories, with women of color represented in small numbers in each academic rank. Contrary to the "model minority" myth, women in the Asian category are not the most represented of the faculty women of color. Hune and Chan (1997) note that Asian Pacific American (APA) men rep-

TABLE 1
Full-Time Women in the Professoriate by Rank, Race/Ethnicity 1997

Women Faculty by Race/Ethnicity	Rank		
	Full Professor	Associate Professor	Assistant Professor
Total Women	32,353	43,522	57,354
American Indian	92	145	285
Asian	1,243	1,633	3,113
Black	1,924	2,674	4,288
Hispanic	767	1,088	1,753
White	28,107	37,586	46,385

SOURCE: *The Chronicle of Higher Education Almanac*, 2001.

resent three-quarters of all APA faculty, and that APAs have the largest gender gap of any racial/ethnic group (p. 57). In the main, faculty women of color primarily occupy the junior, untenured ranks whereas men of color occupy the more senior, tenured ranks. For more information on within group patterns, see Carter and Wilson (1997). The American Council on Education (ACE) data also report lower tenure rates for women of color in tenure-track positions (Wilds, 2000, p. 101).[3]

Interviews with Faculty Women of Color

In this section I draw from and elaborate on interviews with 64 faculty members of color to analyze the consequences of underrepresentation for women faculty of color.[4] Four Asian Pacific American females, fifteen African American females, four Native American females, and eight Latinas were interviewed. Most of these women occupy tenured positions; some are high-level academic administrators.[5] They spoke about the interlocking effects of race and gender bias in the academic workplace.

Manifestation of Interlocking Race and Gender Bias

In general, faculty of color describe racial and ethnic bias in ways that overlap with the concerns raised by women.[6] Yet the interlocking effects of gender and race compound the pressures of the workplace environment for faculty women of color. They perceive that being both minority and female hampers their success as faculty members.[7] This respondent talks about being defined out of consideration for an administrative position because she is an Asian female.

> A [university administrative] position opened up and there were a lot of names mentioned—it was clear that an active [internal] person would be named. I would hear on the grapevine 'so-and-so's' name. . . . I felt that if I were a white male, my name would have been out there. I mean I am sure of that. But it never was and, you know, . . . there is no question in my mind that race and gender influenced that.[8]

Challenges from Academic Old Boy Networks

Although noted in the literature, I uncovered only indirect mention of challenges from academic old boy networks in the interviews. One American Indian woman alludes to this situation in her comment: "This is hard to believe—for a long time I was the only woman of color on this faculty—for years. . . . This campus is very, very white. Almost all of the Indian faculty have been men." Montero-Sieburth (1996) similarly states that Latina professors must overcome more obstacles to gain support for academic advancement, because they are farther removed from the academic old-boy network than Latino or White female counterparts. Although instances of mentorship across and within racial/ethnic and gender groups exists, scarce resources such as tenured faculty positions and chairs of Chicano studies programs can pit Latinas against Latinos. In a similar vein, hooks (1991) states that scholars writing about Black intellectual life focus solely on the lives and works of Black men, ignoring and devaluing the scholarship of Black women intellectuals.

Themes that emerge from the study interviews include: (1) feeling isolated and underrespected; (2) salience of race over gender; (3) being underemployed and overused by departments and/or institutions; (4) being torn between family, community, and career; and (5) being challenged by students. I describe these themes below.

Feeling Isolated and Underrespected

One professor expresses the isolation and the added pressure to perform as a woman of color:

> I have to think about the fact that black females or any female in the field of [name] that has been predominantly a white male profession, has a problem. Many [white] females in the college complain about the fact that up until recently . . . we had never had a full professor in [department name]. It's changing, but it's not changing fast. And then you add to that being the black female who has to be superwoman.

Focusing more on slots filled rather than on expertise or potential programmatic contributions are reported by this newly hired faculty member:

> This one dean . . . was writing down all the federal slots that I would fit in as far as hiring. . . . And he says, "Okay, you're a woman, you're over fifty-five, you're an American Indian," and then he looks at me and grins. He said, "Do you have a handicap?" . . . These schools have to fulfill these guidelines and in getting me they can check a lot of boxes.

Salience of Race over Gender

Despite shared gender discrimination, women faculty of color cannot always expect support from their white female colleagues. A sense that white women have fared and are faring better than are women or men of color exists. This perception speaks to the salience of race over gender. An American Indian woman notes: "Even the white females they've hired still have a problem with minority students and minority perspectives. This is particularly true in [discipline]. It is really dominated by Western European notions."

Montero-Sieburth (1996) points out that "being female does not necessarily guarantee the sympathy of mainstream women toward them nor does it offer entry into mainstream academic domains" (p. 84). She quotes one Latina professor commenting on an experience with White female researchers: "I was always singled out when we needed to present research about underserved communities or make statements about the Latino population; otherwise, my research was ignored" (p. 84).

Gains made by white women resulting from affirmative action are not reflected for women of color. A report by the Women's Environment and Development Organization entitled *Women's Equality: An Unfinished Agenda* (2000) supports this perception:

> Although all women benefit from affirmative action, white women have been the major beneficiaries in the areas of education, contracting and employment. Indeed, white women have progressed to such a significant degree in the area of education that the challenge of affirmative action is no longer in college admissions but in graduate schools and in such areas as engineering and science for which the numbers of women are woefully small. . . . However, affirmative action is still a vital necessity in higher education for women of color, particularly African American and Latino women, whose numbers still lag in undergraduate admissions and in all levels of graduate and professional schools. (www.wedo.org/book.txt)

However, as stated previously, statistical representation is not entirely revealing of the quality of inclusion or equitable distribution in higher education even for white women in the academy. Within the higher education literature (i.e., Glazer-Raymo,1999), exclusion and the "glass ceiling" phenomenon are well documented as affecting all women. Nonetheless, such statistics fuel the perception that white women, not women of color, have been the primary benefactors of affirmative action.

Being Underemployed and Overused by Departments and/or Institutions

Unlike White male faculty members, women of color say they are expected to handle minority and gender affairs, representing two constituencies. An American Indian female faculty member states:

> Issues of pedagogy and cultural diversity and gender are not the province of just women or just faculty of color. I think that happens too often and that puts the faculty of color person or woman on the spot, to kind of convince or persuade—be this change agent. . . . The faculty members feel the added pressure, but are caught in a 'Catch-22' because minority issues are also important to them.

Mitchell (1994) notes that the small numbers of faculty women of color compels them to serve simultaneously as a role model for their profession, race, and gender: "The accountability and time demands that the female ethnic professor encounters are especially pressing, given the fact that minority women occupy even fewer positions than minority men"[9] (p. 387). In retrospect, this African American woman, who did not attain tenure in her first university states: "I am a female and African American. . . . I was doing a lot of things in terms of serving on this board, serving on that board, being faculty adviser for one of the professional fraternities." A Latina notes: "When you are one of three or four Latinos and being a woman, almost every committee wants you to be on it. It gives you opportunities, at the same time, I think, you are expected to do a lot of things not expected of other faculty."

These quotes bring attention to the apparent contradiction and "double whammy" faced by women of color. On the one hand, there is too little opportunity and support for the work that is valued (research) (Fairweather, 1996); on the other hand, there is too much demand for work that is not rewarded (committee work, student club advisor, etc.). In most instances, service does not lead to tenure or to prestigious positions related to committee service, such as administration. Junior faculty members are particularly at risk. Institutional reward systems can deny tenure and security of employment to those who spend more time on service than on research and scholarship, even when the service is assigned to meet institutional needs.

Being Torn Between Family, Community, and Career

Many faculty women of color speak about being "psychologically divided between home and career" or between community and career. They seemingly have two choices: sacrifice family and community commitments for several years to focus almost exclusively on their careers, or honor nonwork commitments, an essential part of their identity, at the risk of not earning tenure. Although policies to accommodate faculty needs for maternity and family leave and childcare are becoming common, little attention has been paid in the academy to minority faculty's desire to contribute actively to their racial or ethnic community (for further discussion see Townsend & Turner, 2000). For example, for many Native Americans, including faculty members (Stein, 1996), "the social value and preeminent goal in life . . . is the survival of the Indian people" (Cross, 1996, p. 335). Similarly, some Chicano faculty "maintain a strong affiliation with their community and feel a strong sense of responsibility to improve the status of other Chicanos in the larger community" (de la Luz Reyes & Halcon, 1988/1996, p. 145; see also Rendon, 1992/1996). For most African American faculty, ties with the Black community are extremely important partly because of "the African heritage of communalism" (Gregory, 1995, p. 7).

Being Challenged by Students

Faculty women of color perceive that they are more likely to have their authority challenged by students than are White male professors.[10] As examples, consider the following:

> If a white male professor says something that's wrong in class, my observation is that even if the students perceive that it's wrong, they may say something outside of class, but they hesitate to challenge a 50+ white male professor. They feel quite comfortable challenging an African American woman in class.
>
> Regarding interaction with students, there's a different expectation for us when we walk in as a minority, they automatically assume that we know less than our colleagues in the same department. . . . It doesn't matter whether it's undergraduate level or graduate level. . . . They challenge females more. . . . So, I wear dark, tailored suits and I am very well prepared. They don't hire us unless we're prepared anyway, but students think we are here because of our color.

Many women faculty of color are called on to advise students of color and others studying in similar fields. Because of their scarcity, faculty women of color can face great out-of-class instructional loads. One junior faculty member of color describes her experience as teacher/mentor:

> As teacher/mentor, the main issue has been balancing. When I first arrived, I was overwhelmed by the amounts of students who came to me to ask for guidance (not always in so many words)—mostly women of color, feeling like most other faculty did not acknowledge their existence. It is difficult to balance this with the research and publication pressures, and course preparation.

Another female faculty member states:

> It is hard to say no, especially on minority issues, when there are so few people. . . . I realize how few people are available [to address these issues]. . . . I sit on 53 doctoral committees. Doctoral students take a lot of time for the dissertation process. I turned down being chair of one doctoral student's committee and she nearly cried. She was a good student studying multicultural issues, but I can't chair these committees. I'll wind up spending all my time correcting dissertations and not doing my own writing.

Andrews (1993) describes this situation as an "emotional drain:"

> The Black woman professor is often called upon to serve as mentor, mother, and counselor in addition to educator in these settings. The consequences of these multifaceted role expectations by students are compounded by the existence of similar demands placed upon Black women by colleagues and

> administrators. . . . If we consider the fact that Black women often also have these same expectations to meet at home, it is abundantly clear that in many cases something has to give. (p. 190)

Cruz (1995) summarizes her reaction to such experiences: “It was not simply that my colleagues and students made me feel different; it was that my difference was equated with inferiority” (In Padilla & Chavez, 1995, p. 93).

Increasing Positive Experiences for Faculty Women of Color

In this section I make recommendations to assure the affirmation, validation, and valuation of contributions faculty women of color bring to the academy.

Validate Service and Teaching

Gregory (1995) recommends the transformation of tenure and promotion criteria by exploring ways to expand the definition of scholarly activity and to place more importance on teaching, service, and curriculum development activities. Baez (2000) stresses that scholars must condemn higher education practices and norms that produce such conflicting situations with differential rewards for faculty of color, especially for minority scholars dedicated to race-based service. Baez contends that “service, though significantly presenting obstacles to the promotion and retention of faculty of color, actually may set the stage for a critical agency that resists and redefines academic structures that hinder faculty success” (p. 363). If service is seen as addressing social justice issues, it can be a source of pride and validation for many minority faculty. It gives them much needed connection with communities of color within and outside of the academy as a whole, which can translate into supportive networks for the individual providing the service. Baez reminds us of the importance and relevance of such service. The key is finding ways to validate it, not to discourage faculty women of color from engaging in it.

Promote Networking and Mentoring

Networking and mentoring are mentioned many times by faculty women of color as key components of individual and group success and progress. Aleman (2000) and Cuadraz and Pierce (1994) identify participation in formal and informal networks as critical to their persistence in academe. Ladson-Billings (1997) speaks about the importance of finding intellectual peers “interested in the issues of race and racism in the same way I was” (p. 57). This Asian American faculty member describes one of her networking/mentoring activities:

> I know a woman who's Chinese. She's in the [name of department] so we have no overlap in the field, but I and another woman in my college who's in computer science have sort of taken it upon ourselves to keep her from getting isolated. We're not even in her college, but we have lunch with her—I like her a lot, so she's become my friend, but we started this by just trying to keep her from being so isolated over there in the [name of department]. I feel so strongly about trying to combat isolation. . . . It's sort of hard because we have families but [it is important to our persistence].

Colleges and universities can facilitate opportunities for faculty women of color to get together. For example, colleges can host social gatherings and academic activities targeted at promoting networking among its faculty women of color. Such activities could include: providing seed money for collaborative research of interest to women of color across disciplines, hold national or local conferences with the intent of bringing together faculty women of color, and host open forums that showcase research conducted by faculty women of color.

Provide Professional Development Sensitive to Campus Political Dynamics

Colleges and universities can provide professional development experiences that assist a new faculty woman of color to overcome challenges of multiple marginality. One example from my own experience is the participation in a teaching development program provided at the University of Minnesota. Participants in this program worked in small groups guided by senior faculty members who were recipients of university teaching awards. In my view, the best mentor teachers grasped the need for faculty members to understand the technical side of teaching as well as the classroom dynamics that can take place when a person of color or a woman steps in front of students who expect a White male teacher. Such mentor teachers can help newer faculty to see and address power relationships that may develop in a classroom that challenge the authority and credibility of a woman of color. Mentor teachers can also encourage new faculty members to accept their leadership role as the professor. Participating in such a program can foster understanding of group dynamics in the classroom. It can affirm different styles of teaching, such as fostering collaborative and small-group work. These programs can be used to inform not only faculty women of color but the rest of the campus community as well.

Break the Conspiracy of Silence

Programs like the one described above can help to uncover the challenges faculty women of color may face in the classroom and on campus generally. Ng (1997) stresses that whether we belong to minority groups or not, educators must "break the conspiracy of silence that has ensured the perpetuation of racism, sexism, and other forms of marginalization and exclusion in the university" (p. 367). In order to address the conflicting and anxiety provoking situations as described in this article, academic administrators and policymakers must acknowledge and come to understand the racial and gender composition of their departments and the effects such composition has on the success or failure of faculty women of color.

Promote a Welcoming Environment

Most faculty women of color contend that a healthy, supportive, rewarding, inclusive environment is good for everyone. Kanter (1977) and others reveal that one crucial component in producing such an environment *is to increase the representation of women of color across the campus*—as students, administrators, and faculty. This representation must also be reflected across student (undergraduate, graduate) and professional ranks (for example, across the faculty ranks of assistant, associate, and full professor). However, Harvey (1991) and others remind us of the critical importance of *developing a campus culture that values and welcomes the contributions made by faculty women of color* to the academic enterprise; that is, acknowledging that the inclusion of faculty women of color contributes to the academy as a whole. Cole (2000) emphasizes this point by stating that diversity—in the people, the ideas, the theories and the perspectives, and experiences and the pedagogy in American higher education—is crucial to a quality education (p. 2). Such support promotes a comfort level that can increase productivity at work and persistence on campus.

Accommodate Conflicts of Commitments

Townsend and Turner (2000) state that institutional leaders must address the challenges and better accommodate conflicts of commitments described by faculty women of color to ensure that these faculty members will stay at their institutions. Specific steps include the following:

1. Identify and acknowledge institutional norms and policies that place women faculty of color at a disadvantage resulting from their family and community commitments.
2. Once these norms and policies are identified, promote the development of new ones that will support rather than punish community and family involvement. Such changes will benefit all faculty who take on a nurturing and supportive role in their communities and families.
3. Include women of color in the identification of problems and solutions.

4. Examine initiatives used by private corporations rated as "family friendly" and evaluate them in light of their appropriateness for a higher education setting.

Internal Rewards and Satisfactions: Contributing to the Reshaping of the Academy

Although confronted by unique pressures, interviews and conversations with faculty women of color reveal the many satisfactions that attract them to and keep them in academia. Foremost among their reasons for becoming faculty members are the intellectual challenge, freedom to pursue research interests, and the opportunity to promote racial/ethnic understanding. The most commonly articulated personal rewards include: satisfaction with teaching, supportive working relationships, and sense of accomplishment. Contributions to scholarship and new knowledge are also important. I will focus here on the desire of faculty women of color to contribute to the reshaping of the academy as described by faculty women of color themselves.

A Sense of Accomplishment

A female American Indian faculty member enthusiastically describes one accomplishment contributing to organizational change and multiculturalism on her campus: "We initiated an endowment to establish an endowed chair for American Indian education, and we managed after years of advocacy to get well over a million dollars for that chair. So the chair was finally established. . . . It will be forever more."

Aligning Service with Research

Consistent with Baez, I have chosen to consider myself a scholar advocate to alleviate some of the tension between service and research. I conduct research to illuminate issues of access and equity for racial/ethnic groups in higher education. As a direct result of this work, I serve racial/ethnic communities in higher education, professional organizations, and the university with which I am affiliated. I have the opportunity to address students as well as administration and faculty audiences who are interested in implementing diversity within academe. Graduate students and faculty of color, at times, come up to me and say that my work provides validation and support for the work in which they are engaged. From this experience, such service, tightly connected with research, confers needed energy, revitalization, and life meaning for my work. Closely aligning the many tasks in academe has helped to sustain my persistence in the field.

Alignment with Communities of Color and Gender

Professor bell hooks, in a 1995 interview for *The Times Higher Education Supplement*, states that "assimilation, touted as an answer to racial divisions, is dehumanizing; it requires eradication of one's blackness so that a white self can come into being" (Griffiths, 1995, p. 20). Doing work that closely aligns oneself to communities of color and gender may provide a way to maintain a sense of self as a woman of color. Delgado-Gaitan (1997) describes this process as a kind of dance: "My life has been a 'TINKLING' dance in which I have hopped between two clanking bamboo sticks, skillfully avoiding getting a foot severed as I jumped in and out. I have searched to find the space that is a synthesis of my worlds, . . . the 'borderland' or meeting ground that synthesizes my identity, experience, feelings, beliefs, and dreams" (p. 37).

Contributions to New Knowledge

Johnetta Cole (2000) asserts that "education promotes critical reflection and stimulates efforts for social change" (p.1). Turner (2000a) and Neumann and Peterson (1997) describe faculty women of color as important contributors to new knowledge in academe. The contributions of one faculty woman of color[11] led to the development of research and teaching in areas such as the history of African American women. Many faculty women of color see themselves as reflecting and projecting their realities in the work that they do. As professors they bring their experience and knowledge into campus dialogues in the classroom, in the literature, and in their communities. Faculty women of color provide guidance and support for young women of color who are their students or who are their colleagues in the professoriate. They advocate for the admission of talented women of color into the student and faculty bodies. Their presence encourages others to pursue individual educational goals. Such contributions by faculty women of color are described in the following quote:

> The academy is shaped by many social forces. More women of color are defining and redefining their roles within it. New ways of thinking about teaching and research have provided spaces for women scholars to challenge old assumptions about what it means to be in the academy. While both the women's movement and black [ethnic] studies movement have helped increase the parameters of academic work, new paradigms emerging from black women's scholarship provide me with a liberatory lens through which to view and construct my scholarly life.[12] The academy and my scholarly life need not be in conflict with the community and cultural work I do (and intend to do)." (Ladson-Billings, 1997, p. 66)

Conclusion

Over the last decade, I have interviewed many women of color who are undergraduate students, graduate students, and who are faculty members. Many of these individuals feel that to succeed in academe requires them to leave themselves, who they are, at the door of graduate education and the tenure process. This loss would be a tragedy for both current and future faculty women of color. Acknowledging who we are and how that affects our approaches to research as well as what we find of scholarly interest may result in a more viable work environment for women faculty of color now and in the future:

> Each person brings a unique cultural background to their experience. Who you are shapes the types of questions you ask, the kinds of issues which interest you, and the ways in which you go about seeking solutions. . . . Although doctoral student and faculty socialization processes are very strong, we must not lose ourselves in the process of fitting in. . . . [Also, as demonstrated here,] the backgrounds [faculty women of color] bring to academia need not take a back seat. . . . They can be placed in the foreground of our work. (Turner, 2000b, p. 133)

By bringing ourselves through the door and supporting others in doing so as well, we can define ourselves in and claim unambiguous empowerment, creating discourses that address our realities, affirm our intellectual contributions, and seriously examine our worlds.

Notes

[1]Throughout this text I use quotations to exemplify issues discussed. Quotations from interviews are observations made by faculty women of color who participated in a study conducted by the author and Samuel L. Myers, Jr. (2000).

[2]Even though common themes are noted in this essay, it is also important to acknowledge that all women of color are not the same and that institutions should not expect them to behave as such. Furthermore, women of color have a range of interests and ways in which they choose to contribute to the academy.

[3]Numbers of full-time faculty in higher education are also noted in the latest American Council on Education (ACE) Status Report (Wilds, 2000, p. 98). These numbers show that women of color comprise 14% of the professoriate, the same percent as reported in *The Chronicle of Higher Education Almanac* for Fall, 1997. Of the total full-time faculty (538,023) in 1995, 187,267 (35%) were women; 26,247 of the women were women of color (14%). These data show that across ranks and tenure status the proportion of full-time women faculty of color is low.

[4]See Turner and Myers (2000) for a detailed description of the study design.

[5]Respondents were located in the biological and physical sciences as well as in the social sciences, humanities, and education. Interviews solicited views on reasons for pursuing an academic career, the pathways that led them to the current position, professional development experiences, experiences as faculty members, general experiences in the academic workplace, future plans and expectations with regard to leaving academia, and recommendations for improving the recruitment and retention of faculty of color.

[6]Respondents of color in the Turner and Myers study (2000) reveal that they face covert and overt forms of racial and ethnic bias. Manifestations of bias described by faculty respondents include: (1) Denial of tenure or promotion due to race/ethnicity; (2) being expected to work harder than whites; (3) having their color/ethnicity given more attention than their credentials; (4) being treated like a token; (5) lack of support or validation of research on minority issues; (6) being expected to handle minority affairs; (7) too few minorities on campus.

[7]Similar results are reflected in *Through My Lens*, a video production by Women of Color in the Academy Project at the University of Michigan (Aparicio,1999). One featured participant speaks of the intersection of race and gender in the academy: "I think that the university is committed but oftentimes has a hard time understanding the position of women of color, certainly understanding how color, how culture and race, make an impact on one's career is a challenge. And then, understanding how being a woman impacts one's career is a challenge as well."

[8]In the literature, Ideta and Cooper (1999) note that "Asian women leaders seem to live in the confines of paradoxes. As Asian females they struggle in organizations which define leaders as primarily male and White. . . . Behaviors which are typical of leaders (displays of power, authority, and fortitude) are considered atypical for women and doubly atypical for Asian women . . . expected to be compliant and subservient in their behavior" (p. 141).

[9]Padilla (1994) refers to being expected to handle minority affairs as "cultural taxation," "the obligation to show good citizenship toward the institution by serving its needs for ethnic representation on committees, or to demonstrate knowledge and commitment to a cultural group, which may even bring accolades to the institution but which is not usually rewarded by the institution on whose behalf the service was performed" (p. 26). He goes on to state that as long as people of color are scarce, such expectations will continue to be the norm.

[10]One White male professor quoted in *Silences as weapons: Challenges of a Black professor teaching white students* (Ladson-Billings, 1996, p. 78) states that students will perceive him as objective, scholarly, and disinterested when teaching issues related to class, race, and gender. On the other hand, minority females teaching in these areas are often seen as self-interested, bitter, and espousing political agendas. His observations mirror comments made by women of color about their classroom experiences (see Committee on Women in Psychology and American Psychological Association Committee, *Surviving and Thriving in Academia: A Guide for Women and Ethnic Minorities*, 1998).

[11]For the story of Darlene Clark Hine see *Shattering the Silences* (Nelson & Pillett, 1997), a highly acclaimed PBS Documentary. The video portrays the lives of eight scholars of color in the humanities and social sciences, illustrating how they transformed and were transformed by their respective disciplines and institutions. These scholars bring new research questions and fresh perspectives to the academic enterprise.

[12]One of the examples Ladson-Billings provides her reader is the influence the work of Patricia Hill Collins (1991) has had on her work. She states that Collins provides a theoretical and conceptual platform on which she rests her methodology. Collins asserts that knowledge claims must be grounded in individual character, values, and ethics. She further contends that "individuals who have lived through the experiences about which they claim to be experts are more believable and credible than those who have merely read or thought about such experience" (p. 209).

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