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outlook

The academic birth rate

Production and reproduction of the research work force, and its effect on innovation and research misconduct

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Most developed nations invest a considerable amount of public money in scientific research for a variety of reasons: most importantly because research is regarded as a motor for economic progress and development, and to train a research workforce for both academia and industry. Not surprisingly, governments are occasionally confronted with questions about whether the money invested in research is appropriate and whether taxpayers are getting the maximum value for their investments.

...questions about the size and composition of the research workforce have historically been driven by concerns that the system produces an insufficient number of scientists

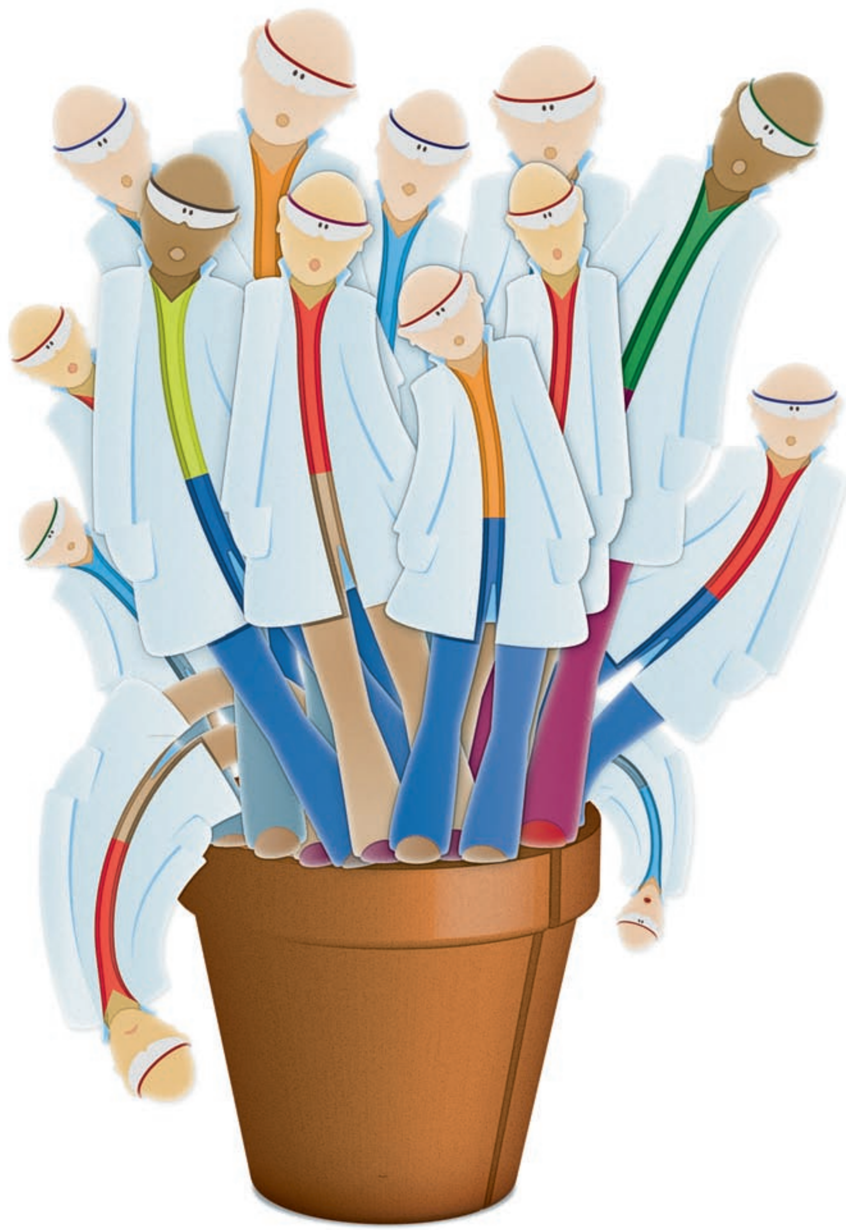
The training and maintenance of the research workforce is a large component of these investments. Yet discussions in the USA about the appropriate size of this workforce have typically been contentious, owing to an apparent lack of reliable data to tell us whether the system yields academic 'reproduction rates' that are above, below or at replacement levels. In the USA, questions about the size and composition of the research workforce have historically been driven by concerns that the system produces an insufficient number of scientists. As Donald Kennedy, then Editor-in-Chief of *Science,* noted several years ago, leaders in prestigious academic institutions have repeatedly rung alarm bells about shortages in the science workforce. Less often does one see questions raised about whether too many scientists are being produced or concerns about unintended consequences that may result from such overproduction. Yet recognizing that resources are finite, it seems reasonable to ask what level of competition for resources is productive, and at what level does competition become counter-productive.

Finding a proper balance between the size of the research workforce and the resources available to sustain it has other important implications. Unhealthy competition—too many people clamouring for too little money and too few desirable positions—creates its own problems, most notably research misconduct and lower-quality, less innovative research. If an increasing number of scientists are scrambling for jobs and resources, some might begin to cut corners in order to gain a competitive edge. Moreover, many in the science community worry that every publicized case of research misconduct could jeopardize those resources, if politicians and taxpayers become unwilling to invest in a research system that seems to be riddled with fraud and misconduct.

The biomedical research enterprise in the USA provides a useful context in which to examine the level of competition for resources among academic scientists. My thesis is that the system of publicly funded research in the USA as it is currently configured supports a feedback system of institutional incentives that generate excessive competition for resources in biomedical research. These institutional incentives encourage universities to overproduce graduate students and postdoctoral scientists, who are both trainees and a cheap source of skilled labour for research while in training. However, once they have completed their training, they become competitors for money and positions, thereby exacerbating competitive pressures.

Questions raised about whether too many scientists are being produced or concerns about the unintended consequences of such overproduction are less common

The resulting scarcity of resources, partly through its effect on peer review, leads to a shunting of resources away from both younger researchers and the most innovative ideas, which undermines the effectiveness of the research enterprise as a whole. Faced with an increasing number of grant applications and the consequent decrease in the percentage of projects that can be funded, reviewers tend to 'play it safe' and favour projects that have a higher likelihood of yielding results, even if the research is conservative in the sense that it does not explore new questions. Resource scarcity can also introduce unwanted randomness to the process of determining which research gets funded. A large group of scientists, led by a cancer biologist, has recently mounted a campaign against a change in a policy of the National Institutes of Health (NIH) to allow only one resubmission of an unfunded grant proposal (Wadman, 2011). The core of their argument is that peer reviewers are likely able to distinguish the top 20% of research applications from the rest, but that within that top 20%, distinguishing the top 5% or 10% means asking peer reviewers for a level of precision that is simply not possible. With funding levels in many NIH institutes now within that 5–10% range, the argument is that reviewers are being forced to choose at random which excellent applications do and do not get funding. In addition to the inefficiency of overproduction and excessive competition in terms of their costs to society and opportunity costs to individuals, these institutional incentives might undermine the integrity and quality of science, and reduce the likelihood of breakthroughs.



My colleagues and I have expressed such concerns about workforce dynamics and related issues in several publications (Martinson, 2007; Martinson *et al*, 2005, 2006, 2009, 2010). Early on, we observed that, "missing from current analyses of scientific integrity is a consideration of the wider research environment, including institutional and systemic structures" (Martinson *et al*, 2005). Our more recent publications have been more specific about the institutional and systemic structures concerned. It seems that at least a few important leaders in science share these concerns.

In April 2009, the NIH, through the National Institute of General Medical Sciences (NIGMS), issued a request for applications (RFA) calling for proposals to develop computational models of the research workforce (http://grants.nih.gov/grants/guide/rfa-files/RFA-GM-10-003.html). Although such an initiative might be premature given the current level of knowledge, the rationale behind the RFA seems irrefutable: "there is a need to […] pursue a systems-based approach to the study of scientific workforce dynamics." Roughly four decades after the NIH appeared on the scene, this is, to my knowledge, the first official, public recognition that the biomedical workforce tends not to conform nicely to market forces of supply and demand, despite the fact that others have previously made such arguments.

Early last year, Francis Collins, Director of the NIH, published a PolicyForum article in *Science*, voicing many of the concerns I have expressed about specific influences that have led to growth rates in the science workforce that are undermining the effectiveness of research in general, and biomedical research in particular. He notes the increasing stress in the biomedical research community after the end of the NIH "budget doubling" between 1998 and 2003, and the likelihood of further disruptions when the American Recovery and Reinvestment Act of 2009 (ARRA) funding ends in 2011. Arguing that innovation is crucial to the future success of biomedical research, he notes the tendency towards conservatism of the NIH peer-review process, and how this worsens in fiscally tight times. Collins further highlights the ageing of the NIH workforce—as grants increasingly go to older scientists—and the increasing time that researchers are spending in itinerant and low-paid postdoctoral positions as they stack up in a holding pattern, waiting for faculty positions that may or may not materialize. Having noted these challenging trends, and echoing the central concerns of a 2007 *Nature* commentary (Martinson, 2007), he concludes that "…it is time for NIH to develop better models to guide decisions about the optimum size and nature of the US workforce for biomedical research. A related issue that needs attention, though it will be controversial, is whether institutional incentives in the current system that encourage faculty to obtain up to 100% of their salary from grants are the best way to encourage productivity."

Similarly, Bruce Alberts, Editor-in-Chief of *Science*, writing about incentives for innovation, notes that the US biomedical research enterprise includes more than 100,000 graduate students and postdoctoral fellows. He observes that "only a select few will go on to become independent research scientists in academia", and argues that "assuming that the system supporting this career path works well, these will be the individuals with the most talent and interest in such an endeavor" (Alberts, 2009).

His editorial is not concerned with what happens to the remaining majority, but argues that even among the select few who manage to succeed, the funding process for biomedical research "forces them to avoid risk-taking and innovation". The primary culprit, in his estimation, is the conservatism of the traditional peer-review system for federal grants, which values "research projects that are almost certain to 'work'". He continues, "the innovation that is essential for keeping science exciting and productive is replaced by […] research that has little chance of producing the breakthroughs needed to improve human health."

If an increasing number of scientists are scrambling for jobs and resources, some might begin to cut corners in order to gain a competitive edge

Although I believe his assessment of the symptoms is correct, I think he has misdiagnosed the cause, in part because he has failed to identify which influence he is concerned with from the network of influences in biomedical research. To contextualize the influences of concern to Alberts, we must consider the remaining majority of doctorally trained individuals so easily dismissed in his editorial, and further examine what drives the dynamics of the biomedical research workforce.

Labour economists might argue that market forces will always balance the number of individuals with doctorates with the number of appropriate jobs for them in the long term. Such arguments would ignore, however, the typical information asymmetry between incoming graduate students, whose knowledge about their eventual job opportunities and career options is by definition far more limited than that of those who run the training programmes. They would also ignore the fact that universities are generally not confronted with the externalities resulting from overproduction of PhDs, and have positive financial incentives that encourage overproduction. During the past 40 years, NIH 'extramural' funding has become crucial for graduate student training, faculty salaries and university overheads. For their part, universities have embraced NIH extramural funding as a primary revenue source that, for a time, allowed them to implement a business model based on the interconnected assumptions that, as one of the primary 'outputs' or 'products' of the university, more doctorally trained individuals are always better than fewer, and because these individuals are an excellent source of cheap, skilled labour during their training, they help to contain the real costs of faculty research.

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However, it has also made universities increasingly dependent on NIH funding. As recently documented by the economist Paula Stephan, most faculty growth in graduate school programmes during the past decade has occurred in medical colleges, with the majority—more than 70%—in non-tenure-track positions. Arguably, this represents a shift of risk away from universities and onto their faculty. Despite perennial cries of concern about shortages in the research workforce (Butz *et al*, 2003; Kennedy *et al*, 2004; National Academy of Sciences *et al*, 2005) a number of commentators have recently expressed concerns that the current system of academic research might be overbuilt (Cech, 2005; Heinig *et al*, 2007; Martinson, 2007; Stephan, 2007). Some explicitly connect this to structural arrangements between the universities and NIH funding (Cech, 2005; Collins, 2007; Martinson, 2007; Stephan, 2007).

In 1995, David Korn pointed out what he saw as some problematic aspects of the business model employed by Academic Medical Centers (AMCs) in the USA during the past few decades (Korn, 1995). He noted the reliance of AMCs on the relatively low-cost, but highly skilled labour represented by postdoctoral fellows, graduate students and others—who quickly start to compete with their own professors and mentors for resources. Having identified the economic dependence of the AMCs on these inexpensive labour pools, he noted additional problems with the graduate training programmes themselves. "These programs are [...] imbued with a value system that clearly indicates to all participants that true success is only marked by the attainment of a faculty position in a high-profile research institution and the coveted status of principal investigator on NIH grants." Pointing to "more than 10 years of severe supply/demand imbalance in NIH funds", Korn concluded that, "considering the generative nature of each faculty mentor, this enterprise could only sustain itself in an inflationary environment, in which the society's investment in biomedical research and clinical care was continuously and sharply expanding." From 1994 to 2003, total funding for biomedical research in the USA increased at an annual rate of 7.8%, after adjustment for inflation. The comparable rate of growth between 2003 and 2007 was 3.4% (Dorsey *et al*, 2010). These observations resonate with the now classic observation by Derek J. de Solla Price, from more than 30 years before, that growth in science frequently follows an exponential pattern that cannot continue indefinitely; the enterprise must eventually come to a plateau (de Solla Price, 1963).

In May 2009, echoing some of Korn's observations, Nobel laureate Roald Hoffmann caused a stir in the US science community when he argued for a "de-coupling" of the dual roles of graduate students as trainees and cheap labour (Hoffmann, 2009). His suggestion was to cease supporting graduate students with faculty research grants, and to use the money instead to create competitive awards for which graduate students could apply, making them more similar to free agents. During the ensuing discussion, Shirley Tilghman, president of Princeton University, argued that "although the current system has succeeded in maximizing the amount of research performed […] it has also degraded the quality of graduate training and led to an overproduction of PhDs in some areas. Unhitching training from research grants would be a much-needed form of professional 'birth control'" (Mervis, 2009).

The greying of the NIH research workforce is another important driver of workforce dynamics, and it is integrally linked to the fate of young scientists

Although the issue of what I will call the 'academic birth rate' is the central concern of this analysis, the 'academic end-of-life' also warrants some attention. The greying of the NIH research workforce is another important driver of workforce dynamics, and it is integrally linked to the fate of young scientists. A 2008 news item in *Science* quoted then 70-year-old Robert Wells, a molecular geneticist at Texas A&M University, "'if I and other old birds continue to land the grants, the [young scientists] are not going to get them." He worries that the budget will not be able to support "the 100 people 'I've trained […] to replace me'" (Kaiser, 2008). While his claim of 100 trainees might be astonishing, it might be more astonishing that his was the outlying perspective. The majority of senior scientists interviewed for that article voiced intentions to keep doing science—and going after NIH grants—until someone forced them to stop or they died.

Some have looked at the current situation with concern, primarily because of the threats it poses to the financial and academic viability of universities (Korn, 1995; Heinig *et al*, 2007; Korn & Heinig, 2007), although most of those who express such concerns have been distinctly reticent to acknowledge the role of universities in creating and maintaining the situation. Others have expressed concerns about the differential impact of extreme competition and meagre job prospects on the recruitment, development and career survival of young and aspiring scientists (Freeman *et al*, 2001; Kennedy *et al*, 2004; Martinson *et al*, 2006; Anderson *et al*, 2007a; Martinson, 2007; Stephan, 2007). There seems to be little disagreement, however, that the system has generated excessively high competition for federal research funding, and that this threatens to undermine the very innovation and production of knowledge that is its *raison d'etre*.

The production of knowledge in science, particularly of the 'revolutionary' variety, is generally not a linear input–output process with predictable returns on investment, clear timelines and high levels of certainty (Lane, 2009). On the contrary, it is arguable that "revolutionary science is a high risk and long-term endeavour which usually fails" (Charlton & Andras, 2008). Predicting where, when and by whom breakthroughs in understanding will be produced has proven to be an extremely difficult task. In the face of such uncertainty, and denying the realities of finite resources, some have argued that the best bet is to maximize the number of scientists, using that logic to justify a steady-state production of new PhDs, regardless of whether the labour market is sending signals of increasing or decreasing demand for that supply. Only recently have we begun to explore the effects of the current arrangement on the process of knowledge production, and on innovation in particular (Charlton & Andras, 2008; Kolata, 2009).

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Bruce Alberts, in the above-mentioned editorial, points to several initiatives launched by the NIH that aim to get a larger share of NIH funding into the hands of young scientists with particularly innovative ideas. These include the "New Innovator Award," the "Pioneer Award" and the "Transformational R01 Awards". The proportion of NIH funding dedicated to these awards, however, amounts to "only 0.27% of the NIH budget" (Alberts, 2009). Such a small proportion of the NIH budget does not seem likely to generate a large amount of more innovative science. Moreover, to the extent that such initiatives actually succeed in enticing more young investigators to become dependent on NIH funds, any benefit these efforts have in terms of innovation may be offset by further increases in competition for resources that will come when these new 'innovators' reach the end of this specialty funding and add to the rank and file of those scrapping for funds through the standard mechanisms.

Our studies on research integrity have been mostly oriented towards understanding how the influences within which academic scientists work might affect their behaviour, and thus the quality of the science they produce (Anderson *et al*, 2007a, 2007b; Martinson *et al*, 2009, 2010). My colleagues and I have focused on whether biomedical researchers perceive fairness in the various exchange relationships within their work systems. I am persuaded by the argument that expectations of fairness in exchange relationships have been hardwired into us through evolution (Crockett *et al*, 2008; Hsu *et al*, 2008; Izuma *et al*, 2008; Pennisi, 2009), with the advent of modern markets being a primary manifestation of this. Thus, violations of these expectations strike me as potentially corrupting influences. Such violations might be prime motivators for ill will, possibly engendering bad-faith behaviour among those who perceive themselves to have been slighted, and therefore increasing the risk of research misconduct. They might also corrupt the enterprise by signalling to talented young people that biomedical research is an inhospitable environment in which to develop a career, possibly chasing away some of the most talented individuals, and encouraging a selection of characteristics that might not lead to optimal effectiveness, in terms of scientific innovation and productivity (Charlton, 2009).

To the extent that we have an ecology with steep competition that is fraught with high risks of career failure for young scientists after they incur large costs of time, effort and sometimes financial resources to obtain a doctoral degree, why would we expect them to take on the additional, substantial risks involved in doing truly innovative science and asking risky research questions? And why, in such a cut-throat setting, would we not anticipate an increase in corner-cutting, and a corrosion of good scientific practice, collegiality, mentoring and sociability? Would we not also expect a reduction in high-risk, innovative science, and a reversion to a more career-safe type of 'normal' science? Would this not reduce the effectiveness of the institution of biomedical research? I do not claim to know the conditions needed to maximize the production of research that is novel, innovative and conducted with integrity. I am fairly certain, however, that putting scientists in tenuous positions in which their careers and livelihoods would be put at risk by pursuing truly revolutionary research is one way to insure against it.

CONFLICT OF INTEREST

The author declares that he has no conflict of interest.

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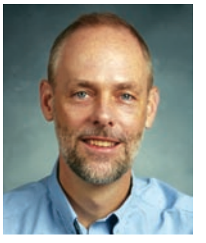

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