

MIT Open Access Articles

A Note on PhD Population Growth in Biomedical Sciences

The MIT Faculty has made this article openly available. **Please share** how this access benefits you. Your story matters.

Citation: Ghaffarzadegan, Navid et al. "A Note on PhD Population Growth in Biomedical Sciences." *Systems Research and Behavioral Science* 32, 3 (November 2014): 402–405 © 2014 The Authors

As Published: <http://dx.doi.org/10.1002/SRES.2324>

Publisher: Wiley-Blackwell

Persistent URL: <http://hdl.handle.net/1721.1/115376>

Version: Final published version: final published article, as it appeared in a journal, conference proceedings, or other formally published context

Terms of use: Creative Commons Attribution-NonCommercial 4.0 International



■ Research Note

A Note on PhD Population Growth in Biomedical Sciences

Navid Ghaffarzadegan^{1*}, Joshua Hawley², Richard Larson³ and Yi Xue³

¹ Virginia Tech, Industrial and Systems Engineering, Blacksburg, VA United States

² Ohio State University, John Glenn School of Public Affairs, Columbus, OH United States

³ MIT, Engineering Systems Division, Cambridge, MA United States

The explosive increase in the number of postdocs in biomedical fields is puzzling for many science policymakers. We use our previously introduced parameter in this journal, the basic reproductive number in academia (R_0), to make sense of PhD population growth in biomedical fields. Our analysis shows how R_0 in biomedical fields has increased over time, and we estimate that there is approximately only one tenure-track position in the US for every 6.3 PhD graduates, which means that the rest need to get jobs outside academia or stay in lower-paid temporary positions. We elaborate on the structural reasons and systemic flaws of science workforce development by discussing feedback loops, especially vicious cycles, which contribute to over-production of PhDs. We argue that the current system is unstable but with no easy solution. A way to mitigate the effects of strong reinforcing loops is full disclosure of the risks of getting PhD. © 2014 The Authors. *Systems Research and Behavioral Science* published by John Wiley & Sons Ltd.

Keywords PhD population; R_0 ; biomedical fields; postdoc; science workforce development

Graduating a new PhD may be very different physically from giving birth to a new baby. Gestation periods are certainly different: 9 months for babies versus four to five years to the hooding ceremony, the moment when the professor brings the new PhD into the world. But they may not be that different conceptually. After all, just as parents love their children, professors often love their students, rejoice in seeing them flourish, and are proud when they successfully defend

their dissertations. It is even common for professors to view their PhD graduates as surrogate sons and daughters; in Germany, a PhD thesis advisor is even called a *Doktorvater* or a *Doktormutter*.

The similarities between parent and professor go even further: they both contribute to population growth. Parents grow the human population; professors grow the population of PhDs. Why does this matter? If a population grows too quickly, resources will become depleted, resulting in poorer economic conditions, stress on public infrastructure, and increased competition for employment opportunities. While the

*Correspondence to: Navid Ghaffarzadegan, Virginia Tech, Industrial and Systems Engineering, Blacksburg, VA, United States.
E-mail: navidg@vt.edu

resources may be different, this is no different for the PhD population than it is for the human population.

More than a century ago, demographers established a parameter to provide a first-order insight into population growth: R_0 , the *basic reproductive number*. R_0 is defined as the mean number of female children a newly born baby girl will have during her lifetime. For the United States R_0 is close to 1, implying a relatively steady population. When R_0 is greater than 1.0, we see exponential population growth.¹

Extending our analogy from giving birth to babies and PhDs, we define R_0 in academia as ‘the mean number of new PhDs that a newly minted tenure-track assistant professor will graduate during his or her academic career’ (Larson *et al.*, 2014). The parameter offers a quick first-order insight about population growth in academia. We estimated R_0 for different fields and during different periods.

Figure 1 offers one example from biomedical sciences. There are various troubling indicators about science workforce in biomedicine. Explosive increase in the number of postdocs, hyper-competition and low rate of grant proposal acceptance, increasing age of first-time grant awardees, and short-term thinking in research projects have been noticed and referred as ‘systemic flaws’ in biomedical research (Teitelbaum, 2008; Alberts *et al.*, 2014). The symptoms can also be seen in the trend of R_0 . The figure implies that R_0 in biology and biomedical sciences is increasing and is far from equilibrium, having reached 6.3—way out of the range of typical reproductive numbers in human population growth.

High R_0 , because it pushes up against resource limitations, has major policy implications. What are the consequences of a high R_0 for PhD population growth?

As Figure 1 shows, the number of tenure-track positions in biomedical sciences in the United States has been relatively constant for three

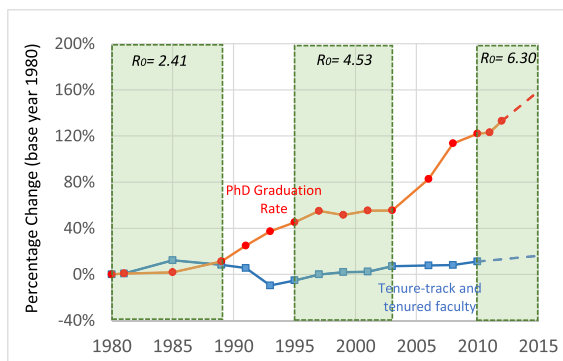


Figure 1 Change in number of tenure-track faculty members and PhD graduation rate in biological and medical sciences, and estimated R_0 in three time intervals²

decades. When the number of positions is constant, the entry rate into academia must equal the exit rate: each entrant must replace the vacancy left by his/her advisor. But if each professor ‘gives birth’ to more than one PhD during that career, and only one can replace him/her—in other words, if R_0 is greater than one, then $(R_0 - 1)$ new PhDs would have to take temporary and lower-paid positions in academia, pursue their futures outside academia, or migrate to other countries. A simple estimation reveals that such outmigration is not the desired plan for more than 95% of PhD graduates.³ Figure 1 implies that given the current PhD ‘birth rate,’ for every new biology and biomedical science PhD who lands a tenure-track academic position there

² Based on authors’ calculation from FASEB (2013). Field definitions are the same as reference FASEB (2013). For career duration, estimations from Larson and Gomez Diaz (2012) is used (before 1995: 17.6 years, and after 1995: 21.6 years). See the discussion on the sensitivity of the results to these assumptions in Larson *et al.* (2014). Final estimated R_0 is very close to NSF’s 2010 reported measures on the percentage of PhD graduates that land academic positions 9–10 years post-PhD and after more than 10 years Post-PhD (NSF estimations: %23.6 and 29.3%, ours: $1/R_0 =$ %22.4 and 29.4% respectively). We estimate that 19.6% of PhD graduates of 2005–2006 have landed or ultimately land tenure track position. NSF reports that in 2010, 16.7% of them have already landed tenure-track positions. Furthermore, our $R_0 = 6.3$ estimation for biological and medical sciences is consistent with Schillebeeckx *et al.* (2013, p.938) statement that ‘there are seven times more PhDs awarded in science and engineering than there are newly available faculty positions.’

³ NSF reports that 22% of PhD students in Biological/agricultural sciences are international and more than 80% of them plan to stay in the United States (FASEB, 2013). Assuming that U.S. citizens prefer to stay home, less than 5% of PhD students have outmigration as their desired plan. This is of course the ‘desired’ plan. Since there are not enough jobs, not all of the 80% end up staying in the US after graduation. Finn (2014) estimates 72% actual stay-rate ten years after graduation.

¹ The concept of R_0 has been also used by epidemiologists to represent growth in the population of people with infectious diseases. Historically, they have borrowed the concept from demographers and have defined R_0 as the mean number of people a newly infected person will infect in a fully susceptible population. For a brief history of R_0 see: Heesterbeek (2002).

are at least 5.3 who ought to be pursuing other opportunities, that is, 84% of new PhD graduates.

Why 'at least'? The duration of an academic career is not necessarily constant, and with longer duration the number of new hires must decline to keep the number of professors constant. We see several indicators of lengthening academic career duration. Since 1980, new faculty hiring has declined with the abolishment of mandatory retirement by the U.S. Congress. Full professors today can stay on past age 65 or even 70. The net result is longer faculty careers and a reduction in the rate of new hires. Our calculations suggest this phenomenon may result in an assistant-professor in-flow reduction of 10-to-20% (Larson and Gomez Diaz, 2012). In addition, high R_0 means more applicants and competition for each job opening in academia. Having fewer openings increases the quality of new hires, which translates to higher likelihood of getting tenure, leading to a declining trend in openings due to longer faculty careers.

Another consequence of high R_0 is the dramatic growth in the number of postdoctoral associates (postdocs). Why has that number in biological and biomedical sciences more than tripled in the past 30 years, now exceeding 40 000 (FASEB, 2013)? Consider another analogy, this one from physics: If water inflow to a bathtub exceeds the outflow, it accumulates and eventually overflows. Similarly, when the PhD production rate (inflow) exceeds outflow as measured by tenure-track faculty hiring rate and industry's intake, PhDs accumulate elsewhere. For many PhDs, the rational decision is to take a temporary position as a way to gain more research experience and publications, and increase their chances of landing a tenure-track position. In addition, more postdoc opportunities in the United States attract PhD inflow from international institutions (Teitelbaum, 2008; Ghaffarzadegan *et al.*, 2014a, 2014b).

Universities benefit from hiring this relatively low-pay, highly trained workforce. Postdocs help faculty members handle more research projects, which further contributes to the growth of new PhDs, a reinforcing feedback loop. Due to the abundance of lower-wage lecturers, in many institutions professors are also encouraged to buy out their teaching responsibilities, which leads

to even greater focus on research and thus to advising even more PhD students. These reinforcing loops lead to higher PhD birth rates.

High R_0 results in underemployment. As the queue for academic appointments increases, more PhDs turn to opportunities in industry and research centers. In certain areas, such as nanotechnology or biomedical engineering, PhDs are hired specifically for their expertise to conduct research and development. For some others, master's or even bachelor's degrees are sufficient. If the jobs that do not require higher-level degrees are taken by the most educated portion of the population, a bachelor's or master's graduate might perceive the PhD degree as a necessary credential to increase the chance of getting the job. The result is more education not because it is necessarily useful, but because it offers an individual competitive advantage, another reinforcing feedback.

Our points echo others on the urgent need to reform doctoral training and research programs (e.g. Cyranoski *et al.*, 2011; Schillebeeckx *et al.*, 2013; Alberts *et al.*, 2014). All these reinforcing feedback loops are rapidly growing the PhD population. Applications to PhD programs in general show no sign of stabilization or decline, despite the time required and the low-paid temporary jobs during and after the degree is earned. Applications to doctoral programs in health and biological sciences have been growing exponentially (FASEB, 2013). As results of the PhD population growth, most new graduates face an environment with ever-declining resources per capita, career instability, and future uncertainties.

How can we escape from all these reinforcing feedback loops? It seems a pertinent policy question.

Many scientists argue for a rapid and significant increase in research funding to protect young, unestablished researchers (Alberts, 2013). We see that as an unsustainable policy. Short-term, abrupt increases in new funding result in medium-term declines in new awards, since inevitable flat budgets need to cover commitments made in the just-completed growth years (Larson *et al.*, 2012). Furthermore, more funding supports exponential growth, resulting in more students, a higher PhD birth rate, more future researchers, and a vicious cycle that leads

to yet more demand for funding (Gomez Diaz, 2012). Nor does it help to increase academic openings: more tenure-track positions lead to more PhD students and graduates, magnifying the reinforcing effect of high R_0 s. Each individual actor—professor, doctoral student, and graduated PhD—is simply acting in her/his best interests.

It seems that the system structure of graduate education, the professoriate, and the national research enterprise are the drivers of doctoral growth.

We know of no easy way to control the PhD population; a good start might be to insist on a fully informed conversation between ‘parent-to-be’ and ‘child-to-be.’ Many students walk into PhD programs hoping to climb the academic ladder to a tenure-track position. It is important that these students understand the post-graduation career landscape *before* investing four or more of their most productive years in PhD programs. Faculty advisors should provide full disclosure of the career statistics of recent PhDs in their research domains: mean number of years as a post-doc; fraction who obtain tenure-track positions; number of applicants per job opening in academia (and, consequently the rejection rates); probability of getting a grant proposal funded by NIH or NSF; mean age at first significant research award; and so on.

Perhaps only full disclosure of the risks and benefits of ‘birth’ will decrease the birth rate. In fact, a good thing about prospective PhDs is that they can decide for themselves whether they wish to be ‘born’!

ACKNOWLEDGEMENTS

The National Institute of General Medical Sciences of the National Institutes of Health supported this work (Grant 5U01GM094141-02). The grant, ‘Developing a Scientific Workforce Analysis and Modeling Framework,’ was awarded to the Ohio State University and MIT. The discussion and conclusions in this paper are those of the authors and do not necessarily represent the views of the National Institutes of Health, the Ohio State University or MIT.

REFERENCES

- Alberts B. 2013. Am I wrong? *Science* **339**(6125): 1252–1252.
- Alberts B, Kirschner MW, Tilghman S, Varmus H. 2014. Rescuing US biomedical research from its systemic flaws. *Proceedings of the National Academy of Sciences* **111**(16): 5773–5777.
- Cyranoski D, Gilbert N, Ledford H, Nayar A, Yahia M. 2011. The PhD factory. *Nature* **472**: 276–279.
- FASEB. 2013. Data compilations. Available from <http://www.faseb.org/Policy-and-Government-Affairs/Data-Compilations/Education-and-Employment-of-Scientists.aspx> [Date of extraction March 20, 2014]
- Finn MG. 2014. Stay Rates of Foreign Doctorate Recipients from U.S. Universities, 2011. *National Center for Science and Engineering Statistics of the National Science Foundation*. Available from <http://orau.org/media-center/news-releases/2014/fy14-09-nearly-two-thirds-foreign-doctorates-are-staying-in-us-10-years-after-graduation.aspx> [Date of extraction August 27, 2014]
- Ghaffarzadegan N, Xue Y, Larson RC. 2014a. Hiring College Graduates to Flip Hamburgers: An Endogenous Theory of Professionalization. *MIT ESD Working Paper Series*.
- Ghaffarzadegan N, Hawley J, Desai A. 2014b. Research Workforce Diversity: The Case of Balancing National versus International postdocs in US Biomedical Research. *Systems Research and Behavioral Science* **31**(2): 301–315.
- Gomez Diaz M. 2012. Unintended effects of changes in NIH appropriations: Challenges for biomedical research workforce development (MSc dissertation, Massachusetts Institute of Technology).
- Heesterbeek JAP. 2002. A brief history of R_0 and a recipe for its calculation. *Acta Biotheoretica* **50**(3): 189–204.
- Larson RC, Ghaffarzadegan N, Diaz MG. 2012. Magnified effects of changes in NIH research funding levels. *Service Science* **4**(4): 382–395.
- Larson RC, Ghaffarzadegan N, Xue Y. 2014. Too Many PhD Graduates or Too Few Academic Job Openings: The Basic Reproductive Number R_0 in Academia. *Systems Research and Behavioral Science* **31**(6): 745–775.
- Larson RC, Gomez Diaz M. 2012. Nonfixed retirement age for university professors: modeling its effects on new faculty hires. *Service science* **4**(1): 69–78.
- Schillebeeckx M, Maricque B, Lewis C. 2013. The missing piece to changing the university culture. *Nature Biotechnology* **31**(10): 938–941.
- Teitelbaum MS. 2008. Structural disequilibria in biomedical research. *Science* **321**: 644–645.