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Too Many Ph.D. Graduates or Too Few Academic Job Openings: The Basic Reproductive Number R_0 in Academia

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Abstract

The academic job market has become increasingly competitive for Ph.D. graduates. In this Note we ask the basic question of "Are we producing more Ph.D.'s than needed?" We take a systems approach and offer a "birth rate" perspective: professors graduate Ph.D.'s who later become professors themselves, an analog to how a population grows. We show that the reproduction rate in academia is very high. For example, in engineering, a professor in the U.S. graduates 7.8 new Ph.D.'s during his/her whole career on average, and only one of these graduates can replace the professor's position. This implies that in a steady state, only 12.8% of Ph.D. graduates can attain academic positions in the U.S. The key insight is that the system in many places is saturated, far beyond capacity to absorb new Ph.D.'s in academia at the rates that they are being produced. Based on the analysis, we discuss policy implications.

I. Introduction

The academic job market has become more and more competitive. Ph.D. graduates are finding it increasingly difficult to land tenure-track academic positions. Candidates are often expected to have several publications in leading journals, putting lots of pressure on them during their training period. Many Ph.D. graduates are unemployed or underemployed (National Science Foundation, 2012; Chapter 3). Reports even state that there are Ph.D. graduates on food stamps (Nichols, 2012).

Nowadays, less than 17% of new Ph.D.'s in science, engineering, and health-related fields find tenure-track positions within 3 years after graduation (National Science Foundation, 2012; Chapter 3). Many Ph.D.'s who do not find tenure-track positions turn to positions outside academia. Others who think that they will have better future opportunities accept relatively low-paying academic jobs such as postdoctoral positions, and stay in the market for a prolonged period (Ghaffarzadegan et al., 2013). Many engineering Ph.D.'s go the entrepreneurial route and become involved in startups. But our focus is academia.

On the demand side, the number of tenure-track positions in a wide range of fields is steady or changing very slowly, if at all (National Science Foundation, 2012; Chapter 5). Except computer science which experienced rapid growth in the past thirty years, and life sciences with the average growth of 1.5% per year, many fields have seen little increase in their faculty slots (National Science Foundation, 2012; Chapter 5). This means new hires can only replace people who leave, as openings are closely tracking retirement and exit rates. Additionally, due to the abandonment of fixed retirement age, the mean duration of a faculty career has increased, resulting in a concomitant decrease in new slots available (Larson and Gomez, 2012).

Considering the trends, a basic question to ask is, "Are we producing more Ph.D.'s than needed?" If yes, how far are we from a steady-state condition in which every qualified applicant interested in a tenure-track academic position can find such a position? We focus on the endogenous nature of the problem (Richardson, 2011), and borrow the concept of R_0 in demography and epidemiology (Sharpe and Lotka, 1911) to shed more light on this problem. Our approach corroborates with several arguments in favor of applying systems approaches to the study of higher education (e.g., Kennedy 2011; Bianchi, 2010; Brown, 1999), while we purposefully keep our model of analysis as simple as possible to provide clear policy insights (Ghaffarzadegan, Lyneis, and Richardson, 2011).

II. The Concept of R_0 for Academia

R_0 denotes the basic reproductive number or rate. In demography R_0 is defined as the mean number of baby girls that a typical newly born baby girl will have in her lifetime. Neglecting infant deaths, if $R_0 > 1.0$, then the population will grow over time. If $R_0 < 1.0$, it will decline. And $R_0 = 1.0$ yields a stable population. For example, R_0 for China and the United States are currently estimated at 0.78 and 1.03 respectively (CIA World Factbook, 2012). In epidemiology, R_0 is the mean number of people that a typical newly infected person will infect during his or her infectious period, assuming that virtually everyone in the population is susceptible to the disease. If a disease has $R_0 > 1.0$ there is initially an exponential growth in number of people infected. For example, R_0 for seasonal flu is typically about 1.2; for H1N1, it was reported to be in the range of 1.4 to 1.6 (Barry, 2009; Brown, 2010); and for the deadly 1918 "Great Influenza", it was estimated to be as high as 4.0 (Astudillo, 2009). Note that, in demography and epidemiology, any R_0 value greater than 1.0 implies exponential growth.

We can use the R_0 metaphor in academia and ***define R_0 to be the mean number of new Ph.D.'s that a typical tenure-track faculty member will graduate during his or her academic career.*** When $R_0 = 1.0$, each professor, on average, graduates one new Ph.D. that can replace him or her. But, assuming a fixed number of faculty slots, $R_0 > 1.0$ means that there are more Ph.D. graduates than existing faculty positions. Depending on magnitude, this may or may not be acceptable since not all of Ph.D. graduates desire academic positions. For $R_0 < 1.0$, the number of Ph.D.'s in a field is declining and the field will eventually die.

For academic fields with $R_0 > 1.0$, an exponential growth in university capacities would be required so that every graduate has an opportunity to assume a tenure-track position. If α is the ratio of the number of Ph.D. graduates interested in tenure-track positions to the total number of Ph.D. graduates, and r is the average growth ratio of faculty slots, we should have $R_0 \leq$ *(1+r·T)/α* in order to have enough academic openings for all Ph.D. graduates, where T is the average period of career.[1] For example, given a yearly growth rate of 1%, and average career of 20 years in academia, assuming 50% of graduates desire tenure-track positions, there will be at least one opening per Ph.D. graduate interested in academic jobs only if $R_0 \leq 2.4$. However, the actual numbers for R_0 are often dramatically outside of this range.

III. R_0 Estimation

We offer an example from our home university, the Massachusetts Institute of Technology. The Institute's total number of tenure-track faculty members has remained

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[1] If α ratio of Ph.D. graduates desire tenure-track positions, to have job for everybody interested we should have: α.
New Ph.D.'s = Exit rate + growth rate   (eq.1)
If number of faculty members is F, using Little's law, the exit rate is F/T, and growth rate is r*F. Then Equation (1) can be written as: α. (R0/T) = 1/T + r   (eq.2)
We can solve the Equation 2 for R0: $R_0 = (1+r*T)/\alpha$ (eq.3)

essentially around 1,000 for over three decades. MIT undertakes about 50 faculty searches each year, looking almost exclusively for young assistant professors. Applying Little's Law (Little, 1961), the mean MIT faculty career length is approximately 1000/50 = 20 years (Larson and Gomez, 2012). Please keep in mind that this is an average, and that some assistant professors will leave in less than seven years, and others obtaining tenure may remain on the faculty for up to 50 years. For the past 15 years, MIT has been producing about 500 Ph.D.'s per year or about 0.5 Ph.D.'s per faculty member per year. This suggests that over a 20-year career of the average MIT faculty member, she/he produces approximately 10 Ph.D.'s. To first order we see that for the 'typical' MIT faculty member, R_0 = 10. Taking a holistic view of academia, only one of these 10 could 'replace' his/her advisor after the advisor leaves the faculty. But that leaves 9 newly minted Ph.D.'s who cannot.

Now we apply R_0 to the field of engineering. We use the 2011 data from the American Society of Engineering Education (ASEE) reporting the number of Ph.D. graduates and faculty members. [2] Average duration of a tenure-track career was approximated to be 20 years (Larson and Gomez, 2012). Results for different engineering fields are depicted in Fig.1. While there is considerable variation across fields, the data give us a rough approximation of R_0 = 7.8 for the field of engineering. That means if the number of faculty positions remains constant, availability of a tenure-track position is for 1/7.8, i.e., 12.8%, of new Ph.D. graduates. In order to have faculty openings in the U.S. for 50% of the graduates, the whole field should grow at an impossible rate of 13% every year. Interestingly, some engineering fields have R_0 much higher than the average, such as biomedical (R_0 = 13.6) and environmental engineering (R_0 = 19.0).

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[2] Data from American Society for Engineering Education's "Engineering by the Numbers" 2011 Report.
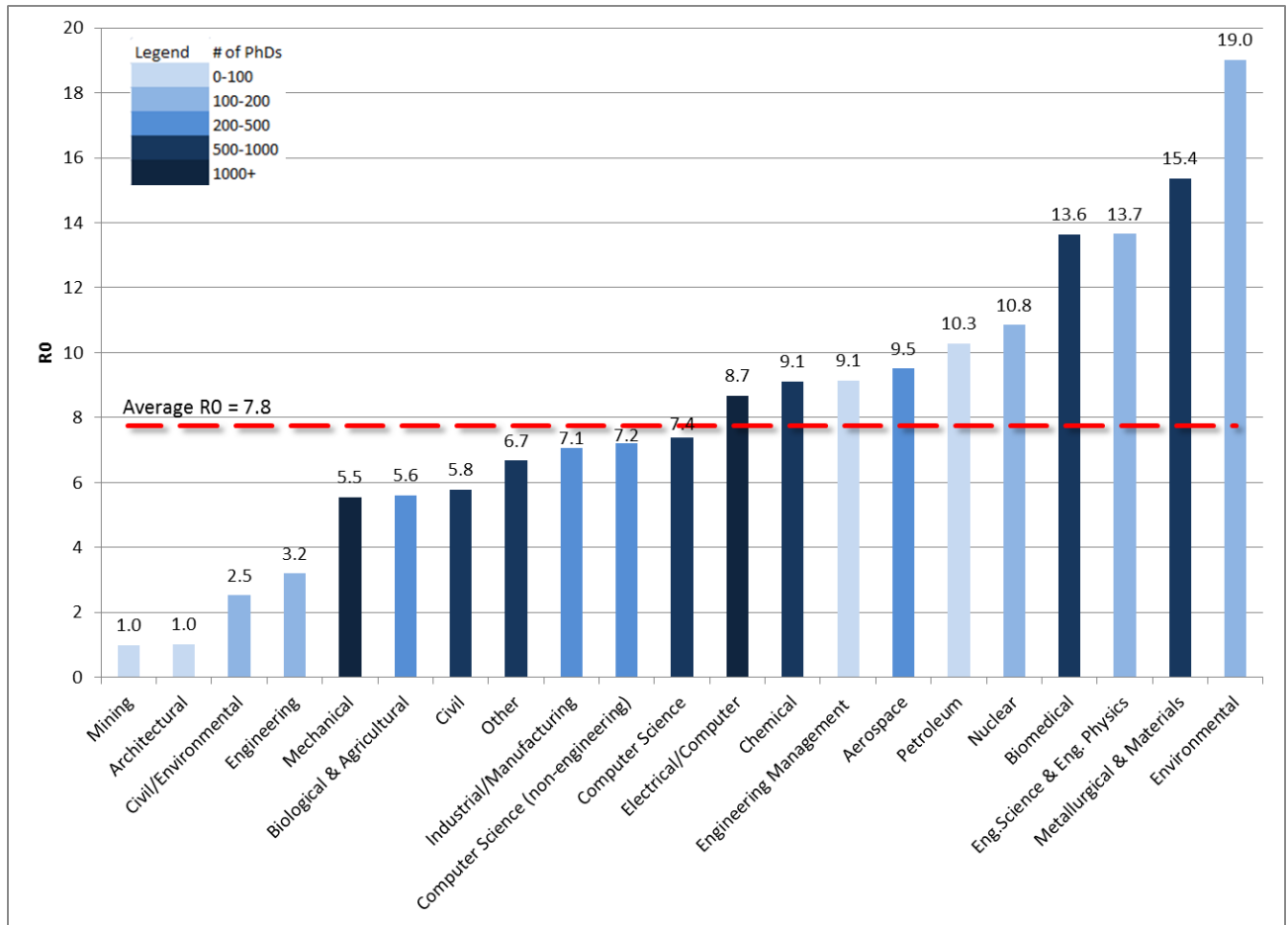http://www.asee.org/papers-and-publications/publications/college-profiles/2011-profile-engineering-statistics.pdf

Figure 1: R_0 Estimation for different Engineering Fields (based on authors' calculation from the

ASEE's 2011 report.[3]

[3] The report is available from http://www.asee.org/papers-and-publications/publications/college-profiles/2011-profile-engineering-statistics.pdf

IV. Policy Insights

By applying the concept of R_0 to academia, we have offered a "birth rate" perspective on challenges that current Ph.D. graduates face in the academic job market. Our back-of-the-envelope calculations suggest that R_0 for the entire engineering field is 7.8, which implies that in a steady state, only 1/7.8 (i.e., 12.8%) of Ph.D. graduates in engineering can attain academic positions in the U.S.[4] The key insight is that the system in many places is saturated, far beyond capacity to absorb new Ph.D.'s in academia at the rates that they are being produced. One result of this is significant growth in postdoctoral appointments (e.g., see Federation of American Societies for Experimental Biology, 2012).

High Ph.D. reproduction in academia follows a similar reinforcing feedback loop (Richardson, 2011; Sterman, 2000) that creates population growth in demography: more faculty members produce more Ph.D. graduates, some of whom become new faculty members. The mechanism may work stronger as an unintended consequence of ramped up government funding on the research enterprise (Teitelbaum, 2008; Gomez et al., 2012; Larson et al., 2012). We see that it can also affect the higher education enterprise, job market challenges, and unemployment and underemployment of Ph.D. graduates.

In demography, any living population eventually meets a ceiling of limited resources. Similarly in academia, the growing Ph.D. population will eventually hit the natural ceiling of limited tenure-track positions. In some fields it already has hit that limit. The physics of the system requires that the oversupply must move to non-academic positions or underemployment in careers that need lesser degrees. Simply increasing the number of faculty slots will not solve

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[4] Even though one third of STEM (Science, Technology, Engineering, and Mathematics) Ph.D.'s are foreign, 66% of them choose to stay in the U.S, so the overall return rate is very small in comparison to the whole population of PhD grates. Reference: R.E. Wasem. Immigration of Foreign Nationals with Science, Technology, Engineering, and Mathematics (STEM) Degrees. Congressional Research Service. (2012) http://www.fas.org/sgp/crs/misc/R42530.pdf

the problem. More openings will increase the numbers of professors, and given their high 'birth rates," the number of future Ph.D. graduates. It's a positive feedback loop.

Our results may appear to be at odds with the national consensus of a current Science, Technology, Engineering, and Math (STEM) crisis in the U.S. We admit that there is a great demand for STEM graduates by American employers and yet many new STEM Ph.D.'s remain underemployed (Gomez et al., 2012). The matching of graduates to STEM careers varies markedly by degree level and specialization. Our analysis has shown that there are more STEM Ph.D.'s than the academic market can absorb, while the number of young people with lesser STEM credentials falls significantly short of market demand. At the education enterprise level, more focus on undergraduate and Masters' level graduates can help ameliorate the STEM workforce supply-demand imbalance.

Given the national need for continued strong doctoral level research, an engineering design puzzle persists: How to design the academic research enterprise so as to perform the research effectively while at the same time reducing the "Ph.D. birth rate" of professors. It may mean that we must accept continued growing use of post-docs and other Ph.D.-level researchers who will never become tenure-track faculty members. But, if this is true, we owe it to these young people, before they embark on a doctoral path, to manage appropriately their career expectations.

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