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Too Many PhD 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 PhD graduates. In this note, we ask the basic question of ‘Are we producing more PhDs than needed?’ We take a systems approach and offer a ‘birth rate’ perspective: professors graduate PhDs who later become professors themselves, an analogue to how a population grows. We show that the reproduction rate in academia is very high. For example, in engineering, a professor in the US graduates 7.8 new PhDs 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 PhD graduates can attain academic positions in the USA. The key insight is that the system in many places is saturated, far beyond capacity to absorb new PhDs in academia at the rates that they are being produced. Based on the analysis, we discuss policy implications.

Keywords

higher education policy; unemployment; R_0; engineering workforce development; research workforce development

INTRODUCTION

The academic job market has become more and more competitive. PhD 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 PhD graduates are unemployed or underemployed (National Science Foundation, 2012; Chapter 3). Reports even state that there are PhD graduates on food stamps (Nichols, 2012).

Nowadays, less than 17% of new PhDs in science, engineering and health-related fields find tenure-track positions within 3 years after graduation (National Science Foundation, 2012; Chapter 3). Many PhDs who do not find tenure-track positions turn to positions outside academia. Others who think that they will have better future opportunities accept relatively

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low-paying academic jobs such as postdoctoral positions and stay in the market for a prolonged period (Ghaffarzadegan *et al*., 2013). Many engineering PhDs go the entrepreneurial route and become involved in startups or work in national research labs or commercial R&D centres. 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 30 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 PhDs than needed?’ If yes, how far are we from a desired 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 favour of applying systems approaches to the study of higher education (e.g. Brown, 1999; Bianchi, 2010; Kennedy, 2011).

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 USA 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 offer the following definition:

> R_0 is defined as the mean number of new PhD’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 PhD that can replace him or her. But, assuming a fixed number of faculty slots, $R_0>1.0$ means that there are more PhD graduates than existing faculty positions. Depending on magnitude, this may or may not be acceptable because not all of PhD graduates desire academic positions. For $R_0<1.0$, the number of PhDs 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 PhD graduates interested in tenure-track positions to the total number of PhD graduates, and r is the average growth ratio of faculty slots, we should have $R_0 \leq \frac{1+rT}{\alpha}$ in order to have enough academic openings for all PhD 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 PhD 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.

R_0 ESTIMATION

Let us start with a simple example from our home university, the Massachusetts Institute of Technology (MIT). The Institute's total number of tenure-track faculty members has remained essentially around 1000 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 7 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 PhDs per year or about 0.5 PhDs per faculty member per year. This suggests that over a 20-year career of the average MIT faculty member, she/he produces approximately 10 PhDs. 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 nine newly minted PhDs who cannot.

Now, we apply R_0 to the field of engineering in academia in the USA. We use the 2011 data from the American Society of Engineering Education reporting the number of PhD graduates and faculty members for all engineering departments in the United States.[2]

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[1] If α ratio of PhD graduates desire tenure-track positions, to have job for everybody interested, we should have

$$\alpha \cdot \text{new PhDs} = \text{exit rate} + \text{growth rate} \quad (1)$$

If the number of faculty members is F, the exit rate is approximately $\frac{F}{T}$, and growth rate is $r \cdot F$. Then, Equation (1) can be written as

$$\alpha \cdot \frac{R_0}{T} = \frac{1}{T} + r \quad (2)$$

We can solve Equation (2) for

$$R_0 : R_o = \frac{1 + r \cdot T}{\alpha} \quad (3)$$

[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 [24 September 2012]

The data are available at an aggregate level for each field. By using the number of PhD graduates in different engineering fields and the number of tenure-track faculty members in those fields, we can estimate the average number of PhD graduates per faculty members in each field. In this dataset, the number of faculty members includes all types of engineering programmes at US institutions, regardless of whether they grant PhD degrees or not (such as 4-year undergraduate colleges). This gives a more accurate estimation of the number of faculty slots available in academia. Multiplying the ratio of PhD graduates to faculty members with the average duration of an academic career provides an estimation of R_0 for different engineering fields in the USA. Based on Larson and Gomez (2012), the average duration of a tenure-track career was approximated to be 20 years. Results for different engineering fields are depicted in Figure 1.

As Figure 1 shows, there is considerable variation across fields with an average of $R_0 = 7.8$ for the whole field of engineering. Put simply, this indicates that an average faculty member in a US higher education institution's engineering department graduates 7.8 new PhDs during her or his career. If the number of faculty positions remains constant, a tenure-track position is only available for 1/7.8, that is 12.8% of new PhD graduates. In order to have faculty openings in the USA for 50% of the graduates, the whole field would need to grow at an improbable rate of 14% every year.

Interestingly, there is considerable variation across the different engineering fields, with a standard deviation of 4.6. Some fields have R_0 much higher than average, such as biomedical ($R_0 = 13.6$) and environmental engineering ($R_0 = 19.0$). Figure 1 also depicts fields with a higher number of PhD graduates in 2011 with darker bars. The field of Metallurgical and Material Engineering, with more than 500 PhD graduates per year, also has a high PhD production rate, indicated by $R_0 = 15.4$.

At the other end of the spectrum, fields such as Mining or Architectural Engineering do not produce as many PhDs per faculty as the other engineering fields with a R_0 close to one, and the number of PhDs graduated in 2011 is low as well, as depicted by the lighter bars. Unless university capacities are shrinking in these two fields, graduates should not have serious problems in finding academic positions.

CAVEATS

We recognize that in using a simple model, several parameters that are not part of our analysis may pose limitations (Ghaffarzadegan et al., 2011). One consideration is that many engineering doctorates are not interested in academic positions and may not even compete for tenure-track positions in academia. Another consideration is that some engineering graduates are foreign citizens who take academic positions outside of the USA.[3] Another factor is inter-field hiring. Engineering doctorates might obtain positions in other fields such as science or business, which would also diminish the gap.

[3] About one third of Science, Technology, Engineering and Mathematics PhDs are non-US citizens (Wasem 2012). Based on a report by National Science Foundation (2012; Appendix 3–20), 77.2% of non-US citizen doctorates of science and engineering who received their degree between 2006 and 2009 intended to stay in the USA. This means 7.5% of PhD graduates in Science, Technology, Engineering and Mathematics fields will not pursue academic careers in the USA.

Overall, these points do not affect our estimation of R_0, and the fact that in a steady state condition, the physics of the system dictates that $1/R_0$ of the population of engineering graduates can find tenure-track faculty positions in engineering departments at US higher education institutions, regardless of their interest in such positions. The rest of the population ($1-1/R_0$) should pursue other careers or find academic positions in other fields or other countries.

Finally, we do not have a precise estimation of the duration of an average academic career. In our estimation of R_0 for the field of engineering, we used the estimate of 20 years from our home institute, MIT (Larson and Gomez, 2012). It is likely that faculty members that leave MIT pursue academic positions in other universities, which implies that we might have underestimated the duration of career in academia, and thus underestimated R_0. In other words, R_0 in engineering fields might be even higher than 7.8.

It is important to state that our intention in this paper was not to introduce an optimal value for R_0, which might depend on several social and behavioral factors such as people's interest in obtaining PhD level education and pursuing academic careers. Our main intention was to provide a simple concept and measurement tool (Richardson, 2013), that can intuitively depict supply side challenges in the academic job market and provide first order, interesting policy insights.

POLICY INSIGHTS

By applying the concept of R_0 to academia, we have offered a 'birth rate' perspective on challenges that current PhD 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 PhD graduates in engineering can attain academic positions in the USA. The key insight is that the system in many places is saturated, far beyond capacity to absorb new PhDs in academia at the rates that they are being produced. In fields where PhD graduates are relatively more interested in finding academic positions, a high R_0 leads to more competition amongst job market applicants. One result of a high R_0 and many doctorates with an interest in academic careers is significant growth in postdoctoral appointments (e.g. see Federation of American Societies for Experimental Biology, 2012; Ghaffarzadegan *et al*., 2013).

High PhD reproduction in academia follows a similar reinforcing feedback loop (Sterman, 2000; Richardson, 2011) that creates population growth in demography: more faculty members produce more PhD 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, exacerbate job market challenges and cause more unemployment and underemployment of PhD graduates.

In demography, any living population eventually meets a ceiling of limited resources. Similarly in academia, the growing PhD 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 be underemployed in careers that require lesser degrees. Simply increasing the number of faculty slots will not solve the problem. More openings will increase the numbers of professors, and given their high 'birth rates,' the number of future PhD graduates. It is a positive feedback loop.

Our results may appear to be at odds with the national consensus of a current Science, Technology, Engineering and Mathematics (STEM) crisis in the USA. We admit that there is a great demand for STEM graduates by American employers and yet many new STEM PhDs 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 PhDs 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 'PhD birth rate' of professors. It may mean that we must accept continued growing use of postdocs and other PhD-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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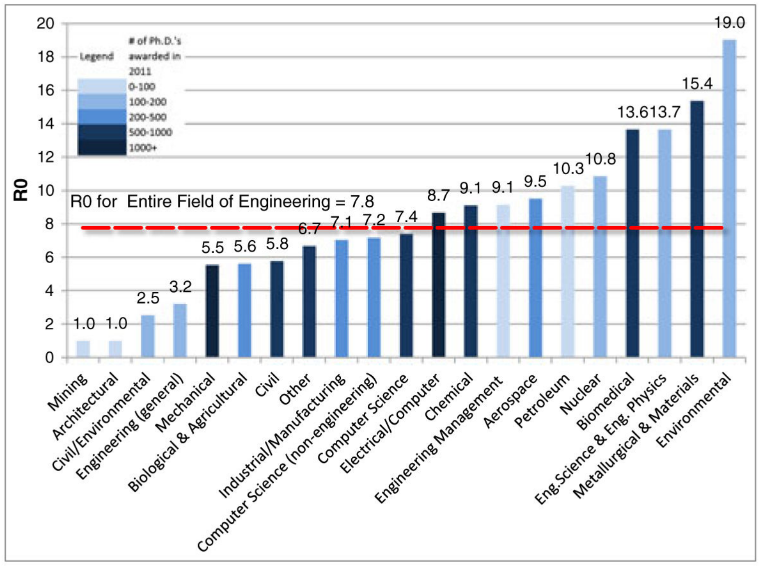

Figure 1.

R_0 estimation for different engineering fields (based on authors' calculation from the American Society of Engineering Education report[4])

[4]The report is available from http://www.asee.org/papers-and-publications/publications/college-profiles/2011-profile-engineering-statistics.pdf [24 September 2012].