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### STEM Crisis or STEM Surplus? Yes and Yes

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# STEM Crisis or STEM Surplus? Yes and Yes

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## Abstract

Over the last decade, there has been significant concern regarding a shortage of science, technology, engineering, and mathematics (STEM) workers to meet the demands of the labor market. At the same time, many experts have presented evidence of a STEM worker surplus. The literature tends to lean heavily in one direction or the other: one side proclaims an impending STEM crisis and the other side asserts a STEM surplus. This paper tries to reconcile the “STEM Crisis” vs. “STEM Surplus” debate by segmenting the STEM labor market into different industries, occupations, and skill levels. We conduct an in-depth analysis of the STEM labor market using a comprehensive literature review in conjunction with sources such as employment statistics, newspaper articles, and authors’ interviews with company recruiters. Our findings indicate a significant heterogeneity in the STEM labor market. While the academic sector is generally oversupplied, the government and government-related sector has shortages in specific areas such as nuclear engineering, materials science, and electrical engineering, as well as cybersecurity and intelligence. The private sector also has specific shortages for positions such as petroleum engineers, data scientists, and software developers. At the same time, there are surpluses for graduates in areas such as chemistry and physics. The demand and supply also vary according to location and U.S. citizenship. Based on our analysis, we discuss policies to address the STEM workforce demand and supply.

# 1 Introduction

*“Economic projections point to a need for approximately 1 million more STEM professionals than the U.S. will produce at the current rate over the next decade if the country is to retain its historical preeminence in science and technology.” – PCAST (2012)*

*“Unemployment rates within STEM fields generally ... are often higher than they’ve been in years—a sign that there is a shortage of jobs, not workers.”—  
Michael Anft (2013)*

Over the past decade, there has been significant concern regarding the adequacy of the science, technology, engineering, and math (STEM) workforce. Opposing sides paint a polarizing picture of the STEM workforce: Is there a “STEM Crisis” or a “STEM Surplus”? Our answer is that there are both.

STEM covers a diverse array of occupations from mathematicians to biomedical researchers, and at degree levels from bachelor to PhD. Some occupations may have a shortage of qualified talent, such as nuclear and electrical engineering PhDs who are U.S. citizens; in other areas, such as biology PhDs aiming to become professors, there is a surplus. While many studies have examined the science and engineering workforce in the aggregate (Lowell and Salzman 2007; Carnevale, Smith, and Melton 2011; RAND Corporation 2004), there has been little analysis to identify specific areas of STEM shortage or surplus. Using a “taxicab queueing model” as a framing metaphor, this paper examines the *heterogeneous nature* of STEM occupations by studying distinct STEM disciplines and employment sectors based on current literature and statistical data as well as anecdotal evidence from newspapers.<sup>1</sup> To augment our findings, we interviewed company recruiters from a wide range of industries to gauge the ability of employers to fill open positions. We evaluate these interviews with labor market data and scholarly work to understand better, from a recruiter’s perspective, the hiring needs and difficulties for STEM workers. Based on the analysis, we discuss policies to address the STEM workforce demand and supply.

## 2 The Ongoing STEM Debate

Numerous reports detail the growing concern of policymakers and industry leaders regarding a shortage in the STEM workforce believed necessary to sustain the United States’ innovation enterprise, global competitiveness, and national security (Business Roundtable 2005; National Science and Technology Council 2000; National Science Board 2003). Most notable is the National Academies’ report *Rising Above the Gathering Storm* (National Academy of Sciences 2007), which called for improvements in K-12 science and mathematics education and increasing the attractiveness of higher

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<sup>1</sup> Numerical and graphical results of the taxicab queueing model can be found in Xue’s thesis work (Xue 2014).

education, among other recommendations. It highlighted troubling factors in a number of areas: low STEM retention rates; relative decline of U.S. citizens in science and engineering graduate school enrollment; and lower percentages of STEM graduates compared to other developed countries. These sentiments were echoed in a 2012 report by the U.S. Congress Joint Economic Committee (U.S. Congress Joint Economic Committee 2012), which stated that the current STEM workforce was falling short of demands in both STEM and non-STEM occupations. According to the President's Council of Advisors on Science and Technology (PCAST), the United States would need to increase yearly production of undergraduate STEM degrees by 34 percent over current rates to match the forecast demand for STEM professionals (President's Council of Advisors on Science and Technology 2012).

There are, however, many who disagree. Testifying before the U.S. House of Representatives, Teitelbaum (2007a) opined that there are no general shortages of scientists and engineers. He went even further to state that there was evidence suggesting surpluses: that there were significantly more science and engineering graduates in the United States than attractive positions available in the workforce. Lowell and Salzman (2007) have pointed to the disproportionate percentage of bachelor's degree STEM holders not employed in STEM occupations. Looking at the STEM labor market, Salzman et al. (2013) concluded that for every two students graduating with a U.S. STEM degree, only one is employed in STEM, and that 32 percent of computer science graduates not employed in Information Technology attributed it to a lack of available jobs. In 2014, the U.S. Census Bureau (2014) reported that 74 percent of those who have a bachelor's degree in STEM are not employed in STEM occupations.

### **3 Taxicab Queueing Metaphor**

The taxicab queue is a classic queue theory problem, first documented in the literature by Kendall (1951). Using the taxicab queueing metaphor, each taxi-passenger system represents a narrow segment of the STEM employment system. Employers or job positions can be thought of as a finite number of taxicabs and STEM workers can be thought of as a stream of would-be passengers. We have employers searching for employees, analogous to a queue of taxis waiting for passengers, and another queue of STEM workers searching for jobs, similar to how passengers wait for taxis. If the number of employers searching for employees is greater than the number of STEM workers, we have a queue of taxis, which manifests in the real world as a STEM shortage. If the number of STEM workers is greater than the number of employers, we have a queue of STEM workers, which means there is a STEM surplus. If the number of employers and STEM workers is equal, we have a momentary match between supply and demand and there is no queue.

This queueing theory framework provides a novel approach to looking at the STEM labor market and the STEM crisis versus surplus conundrum. The demand and supply of STEM workers varies by market and location in much the same way that the demand and supply of taxicabs and passengers. Just as there are separate lines for taxicabs that accept credit cards versus ones that do not, there are distinct lines for each type of STEM occupation. The demand for doctorates in mechanical engineering is different from the

demand for bachelors in mechanical engineering, and the supply of doctorates in biomedical sciences is different from the supply of doctorates in physics. There are also spatial differences. A queue of waiting taxis may be a common sight at an airport, but outside a hotel it may be more common to see a queue of waiting passengers. Analogously, the demand for petroleum engineers in Texas is different from the demand for petroleum engineers in Massachusetts. There may not be a STEM “crisis” in all job categories, but instead in select ones at certain degree-levels and in certain locations. This model also captures the probabilistic nature of supply and demand markets. The times at which both employers and STEM workers enter the job market are uncertain. A job segment that traditionally has a shortage of workers may at some times have a surplus and *vice versa*. Thus, it is probably far more accurate to state that within STEM job categories there is a “crisis” or a “surplus” depending on the circumstances at a given time when the categories are investigated.

## **4 Methodology and Data**

The STEM supply and demand dynamics involve many actors: students, current STEM workers, educational institutions, government, and the private sector. Depending on the STEM segment, changes in each of actors influence the market to varying degrees. Detailed data on STEM labor markets tend to be sparse. On the supply side, there are problems with underreporting of surpluses. The reported unemployment rate of STEM graduates is consistently low, but does not reflect those who are underemployed or have switched fields. On the demand side, there is little available data on job openings in aggregate for various STEM job segments.

We analyzed the STEM labor market using an in-depth literature review of available data sources in conjunction with sources such as newspaper articles. To obtain first-hand data, we also interviewed talent recruiters for organizations from a wide variety of industries including government contractors, media companies, IT companies, research institutes, startups, and consulting agencies. Due to the small sample size ( $n = 18$ ), the interviews may be limited in generalizability. Hence, interview results are included only when they supplement the literature or fill gaps. Our objective is to highlight the heterogeneity of the demand and supply for STEM workers, rather than paint a complete picture of the supply and demand across all STEM job segments.

## **5 Literature Survey and Results**

As mentioned above, the literature on the supply and demand of STEM workers tends to lean heavily in one direction or the other: with one side proclaiming an impending STEM crisis and the other side asserting a STEM surplus. To understand better this conundrum, we examine the STEM market at a deeper level. By segmenting the STEM labor market into different disciplines, sectors, and skill levels, we find there is considerable heterogeneity in the supply and demand of workers. Our analysis of the STEM labor market is broken down into three main employment sectors: academia, government, and the private sector, and then further narrowed down by specific job categories and disciplines.

## 5.1 Academia

The academic employment sector considered here comprises two- and four-year colleges, universities, and university-affiliated research institutes (UARIs). STEM graduates at the bachelor's level are typically employed as research assistants, research associates, or technicians. Master's level graduates are predominantly employed as research associates and staff scientists or instructors or lecturers at teaching institutions. The minimum requirement for a tenure-track professor position is a PhD, with many positions now even requiring one or more postdoctoral appointments (postdocs). In the academic employment sector, we found no literature proclaiming a shortage of STEM graduates. On the contrary, there are numerous articles about how the lack of permanent faculty positions forces young PhDs to take low-paying temporary positions as postdocs and adjunct faculty.

Many students enter doctoral programs with the intent of climbing the academic ladder and obtaining tenure as a professor. But in many fields, open positions are difficult to find. In fact, the intensified competition for assistant professor openings has resulted in higher-quality new hires, meaning that a greatly increased chance of obtaining tenure. This will further exacerbate the shortage of STEM faculty slots, as the number of new slots will decline as tenure probability increases.

To examine the production of PhDs for the academic job market, Larson et al. (2014) borrowed the concept of  $R_0$ , the basic reproduction number, and applied it to academia. For academia,  $R_0$  was defined as the mean number of new PhDs 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. When the number of faculty slots has remained almost constant,  $R_0 > 1.0$  means there are more doctorates than existing faculty positions.

Using this method, we estimate  $R_0$  for all fields in the United States (we assume average career duration to be 20 years, as in Larson and Gomez (2013)). We use 2012-2013 data from the College and University Professional Association for Human Resources (CUPA-HR), which reports the number of tenured and tenure-track faculty at 794<sup>2</sup> institutions in the United States and data from the Integrated Postsecondary Education Data System (IPEDS), which has the number of PhDs awarded in 2012 for those institutions. We group disciplines by CIP-code<sup>3</sup>, a taxonomic scheme devised by the U.S. National Center for Education Statistics to track fields of study. Figure 1 shows that calculated  $R_0$  varies considerably across the broad disciplines.

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<sup>2</sup> While only 294 of these 794 institutions have doctoral programs, the number of faculty used in the  $R_0$  calculation is for all institutions, since these are still tenured and tenure-track faculty positions.

<sup>3</sup> Disciplines were included only if there were data available for both the number of PhDs and the number of faculty.

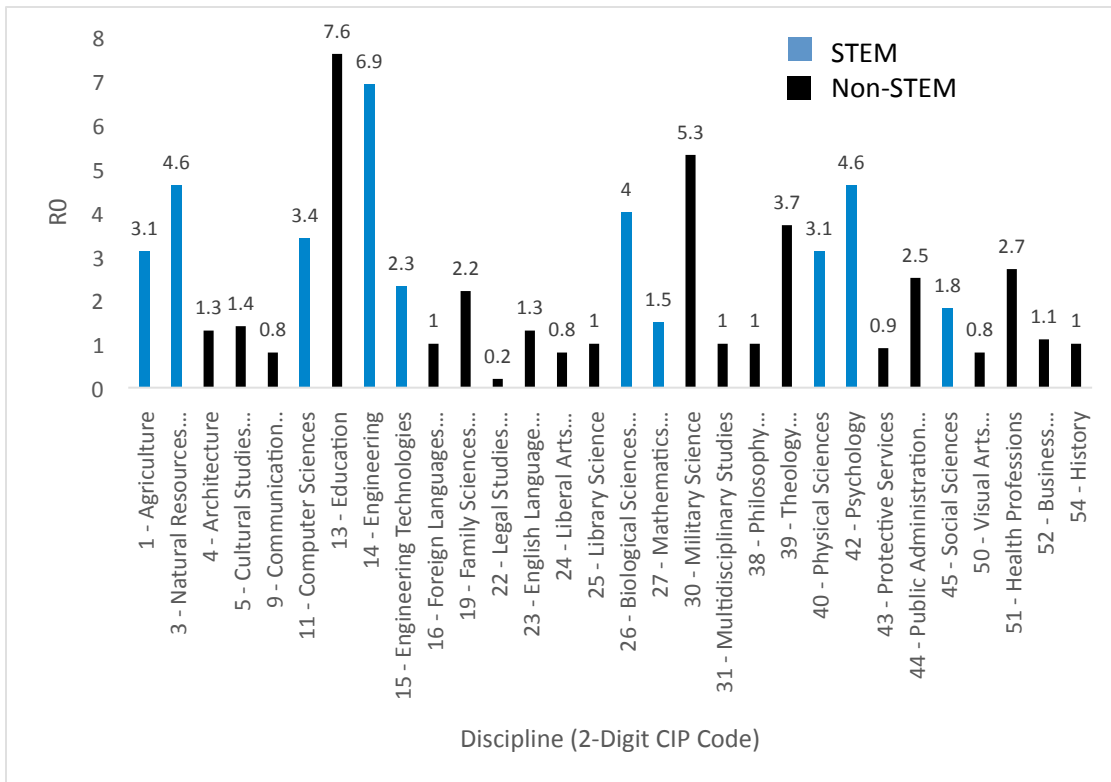


Figure 1.  $R_0$  for 794 U.S. institutions by CIP-code, indicating the heterogeneity across 30 different disciplines. Data sources: CUPA-HR and IPEDS.

While the number of PhDs has been climbing steadily, the number of professor positions has remained almost constant in most fields except the biomedical sciences and computer sciences (National Science Board 2014). A higher  $R_0$  indicates that more PhDs are competing for tenured and tenure-track faculty slots, provided that the number of positions remains constant. For example, an  $R_0 = 6.9$  indicates a tenure-track position is available only for 14 percent (1 out of 6.9) of new PhDs in engineering. From our calculations, all STEM fields have an  $R_0 > 1$ , indicating there are more PhDs eligible for academic positions than openings, assuming no growth in the number of tenure-track faculty slots.

These  $R_0$  statistics confirm anecdotal accounts. Faculty openings today often attract hundreds of qualified applicants (Benderley 2010). Sauermann and Roach (2012) studied the preferences of science PhD students ( $n=4,109$ ) and found that the majority considered a faculty research career to be an “extremely attractive” career path. However, only a lucky few go directly from graduate school to a tenure-track faculty position. In 2010, less than 15 percent of new PhDs in science, engineering, and health-related fields found tenure-track positions within three years after graduation (National Science Board 2014). For PhDs in the life sciences, the figure was only 7.6 percent. Most who want an academic career join academia as postdocs or adjunct faculty, hoping to vie for a tenure-track faculty position in the future.

These findings are consistent with many others in the literature. Michael S. Teitelbaum, vice president of the Sloan Foundation, highlighted the poor prospects for recent doctorates and postdocs (Teitelbaum 2007b). The RAND Corporation pointed out that the length of post-baccalaureate study for the biosciences has increased considerably from between seven and eight years to between nine and twelve, and that many are unable to secure stable employment with tenure until their late thirties (RAND Corporation 2004). This finding was substantiated in a National Research Council report, *Bridges to Independence*, which focused on the poor state of biomedical research careers and urged immediate reform to enhance the quality of training and foster opportunities for young researchers to conduct independent research (National Research Council 2005). While this academic surplus began in the biosciences, it has now extended to encompass many STEM fields such as astronomy, meteorology, and high-energy physics (Benderley 2010). In the academic employment sector, we find no evidence of any shortages. It appears there is a significant mismatch between the supply of PhDs desiring an academic career and the availability of tenure-track faculty positions (Ghaffarzadegan et al. 2014). While the degree of mismatch varies according to discipline, we have long queues of PhDs competing for nearly all STEM-related faculty positions.

## **5.2 Government and Government-Related**

The government and government-related employment sector considered here comprises different branches of civilian government organizations such as the Department of Defense (DOD) and National Laboratories, the military, as well as defense and aerospace contractors and research institutes, which require employees that hold U.S. citizenship and certain security clearances. This section synthesizes reports produced by the National Academies that studied the hiring needs of the U.S. Air Force, the U.S. DOD, and anecdotal accounts from the authors' interviews.

The National Research Council Committee (2010) states that the Air Force had a robust supply of STEM-degreed personnel to meet its recruiting goals for STEM positions, with a few exceptions. The Air Force Personnel Center (AFPC) found staffing gaps in electrical engineering, operations research, quantitative psychology, physics, nuclear engineering, and systems engineering. The AFPC was specifically concerned with graduates with advanced degrees. The Aeronautical Systems Center Commander also identified shortages in areas such as electromagnetics, structures, software, reliability and maintainability, and manufacturing engineering.

Similarly, the National Academy of Sciences Committee (2012), charged with identifying the needs for the U.S. DOD and the U.S. defense industrial base, found that DOD representatives almost unanimously stated that there was not a STEM workforce crisis, but that there were specific areas in which needs were not being met. For example, there were 800 funded positions were open for 90 days or more for systems engineers and other STEM workers, as well as opportunities for cybersecurity and intelligence professionals. The aerospace and defense industry also have experienced difficulty in hiring mechanical engineers, systems engineers, and aerospace engineers.

These sentiments were generally echoed in our interviews. One participant, a recruiting manager for a research institute, said that hiring at the bachelor's level was relatively



easy, but hiring those with advanced degrees proved more challenging because of skill set mismatches.<sup>4</sup> He stated that while there were many applicants from the mechanical, aeronautical, and bioengineering disciplines, there were shortages of electrical engineers at the doctoral level. Software development skills at all degree levels were also in high demand.

Another recruiting manager for a research institute also found difficulties hiring those with advanced degrees in computer sciences and computer engineering.<sup>5</sup> Due to budget stipulations, salaries his institute offered could not compete with those in the private sector.

While foreign nationals can generally be brought in to bridge skill gaps in academia and the private sector, this is currently not an option in many areas for the government and defense-related contractors. The International Traffic in Arms Regulations dictate that information and material related to defense and military technologies may be shared only with U.S. citizens unless a specific exemption is obtained. A hiring manager for a large government contractor found significant shortages in hiring for PhDs in fields such as nuclear engineering, materials science, and thermohydraulic engineering.<sup>6</sup> While the contractor requires only a dozen or so of each, the supply of U.S. citizens with doctorates in these fields is small.

An engineering startup recruiter told us of no problems finding materials science PhDs who were U.S. citizens.<sup>7</sup> While they received dozens of applications from qualified foreign nationals, the government funding required U.S. citizenship.

In the government and government-related employment sector, the authors find no evidence of widespread STEM shortages; however, there may be shortages at the advanced-degree level due to citizenship and security clearance requirements.

### **5.3 Private Sector**

Much of the literature on the STEM crisis emanates from concerns about shortages or surpluses in the private-sector STEM labor market; however, it is generally discussed in broad terms, referencing the STEM workforce as a whole. For example, the PCAST report called for an additional 1 million STEM degrees over the next decade (President's Council of Advisors on Science and Technology 2012). Similarly, many studies refute the claim that there are STEM shortages at the aggregate level and point to shortages only in specific fields (Lowell and Salzman 2007; Teitelbaum 2007a). However, the disciplines and degree levels at which graduates are actually in demand is unclear.

This section presents our findings from a literature review and interviews.

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<sup>4</sup> Research Institute A, primarily involved in U.S. government projects that require U.S. citizenship.

<sup>5</sup> Research Institute B, primarily involved in U.S. government projects that require U.S. citizenship.

<sup>6</sup> Engineering Company A, government contractor that requires U.S. citizenship, no dual citizenship holders.

<sup>7</sup> Engineering startup.

### 5.3.1 Shortages

There are many anecdotal accounts that break down disciplines further and identify specific areas with a shortage of STEM talent. Frenzel (2013) identified shortages among analog/linear and RF/microwave design engineers and skilled programmers. Rothwell (2012), a senior research analyst at Brookings Institution, analyzed the Conference Board's Help-Wanted Online Series and found that in 2010 there were seven job openings in computer occupations for every graduate with a relevant computer major. Wanted Analytics, which aggregates job listings from all over the Web, reported in 2013 that help-wanted ads for software developers were up 120 percent over the previous year (Lombardi 2013).

From our interviews with recruiters, we also find software development skills to be the most in demand. Experienced mobile application developers are especially coveted.<sup>8</sup> In certain cases, it does not matter whether a candidate has a bachelor's degree in a specific area. Companies are looking for candidates with hands-on experience in software development through hack-a-thons, extracurricular projects, and internship experiences.<sup>9,10,11</sup> These anecdotal accounts are supported by the falling unemployment rate for software developers, from 4 percent in 2011 to 2.8 percent in 2012 and down to 2.2 percent in the first quarter of 2013 (Thibodeau 2013). The recent "big data" trend has also sparked demand for data scientists in all areas, from health care to retail (de Lange 2013).

Due to increasing energy prices and new technologies for domestic extraction for oil and gas, petroleum engineers are now in high demand, even though it was an unattractive and declining position throughout the 1980s and 1990s (Porretto 2007; Wadhwa 2011; Teitelbaum 2014). As an indicator, the real wages for petroleum engineers have increased (Salzman, Kuehn, and Lowell 2013).

There is also demand for STEM skills below the bachelor's level. A 2011 survey of manufacturers found that as many as 600,000 jobs remain unfilled due to lack of qualified candidates for technical positions requiring STEM skills, primarily in production (machinists, operators, craft workers, distributors and technicians) (The Manufacturing Institute and Deloitte 2011). There is concern that very few people are pursuing employment in the skilled trades (Wright 2013).

### 5.3.2 Surpluses

At the same time, there have been areas with surpluses of STEM talent, most notably biomedical PhDs. An NIH blue-ribbon panel found an increasing number of biomedical PhDs working in science-related occupations that do not involve research and even that do not require graduate training in science (National Institutes of Health 2012). Chemistry and biomedical graduates have also taken a hard hit due to the downsizing and offshoring of biotechnology, chemical, and pharmaceutical jobs (Cyranoski et al. 2009; Bloom 2011). Since 2000, U.S. pharmaceutical companies have cut 300,000 jobs (Vastag 2012). Downsizing increased the unemployment rate among chemists in 2012 to

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<sup>8</sup> Media Company A.

<sup>9</sup> Media Company A.

<sup>10</sup> Engineering Company B.

<sup>11</sup> IT Company D.

4.6 percent, the highest in 40 years. One recruiter we interviewed said he found that many chemical engineering college graduates were seeking employment in software development.<sup>12</sup> Among young PhDs, the situation is even worse; only 38 percent of newly minted chemistry PhD were employed in full-time, non-postdoc positions in 2011, down from 51 percent in 2008 (Morrissey 2012). New chemical engineering PhDs fared better, with a full-time non-postdoc employment rate of 61 percent.

In 2010 and 2011, the unemployment for electrical engineers held at 3.4 percent, but spiked to 6.5 percent in the first quarter of 2013. While recruiters in the government and government contractor space had concerns about hiring electrical engineers, these concerns did not surface in our interviews with private-sector recruiters, suggesting that the hiring challenge in the government space is probably due to the U.S. citizenship requirement.

Because the unemployment rate for STEM PhDs is generally low, a more useful indicator of job market strength is to look at the number of STEM PhDs who accept potentially permanent positions compared with those who accept postdocs. A significant number of physics PhDs are accepting postdocs and other temporary positions (60% in 2010 compared to 40% before the dot.com bust), indicating that the demand for physics PhDs is not high (see Figure 2).

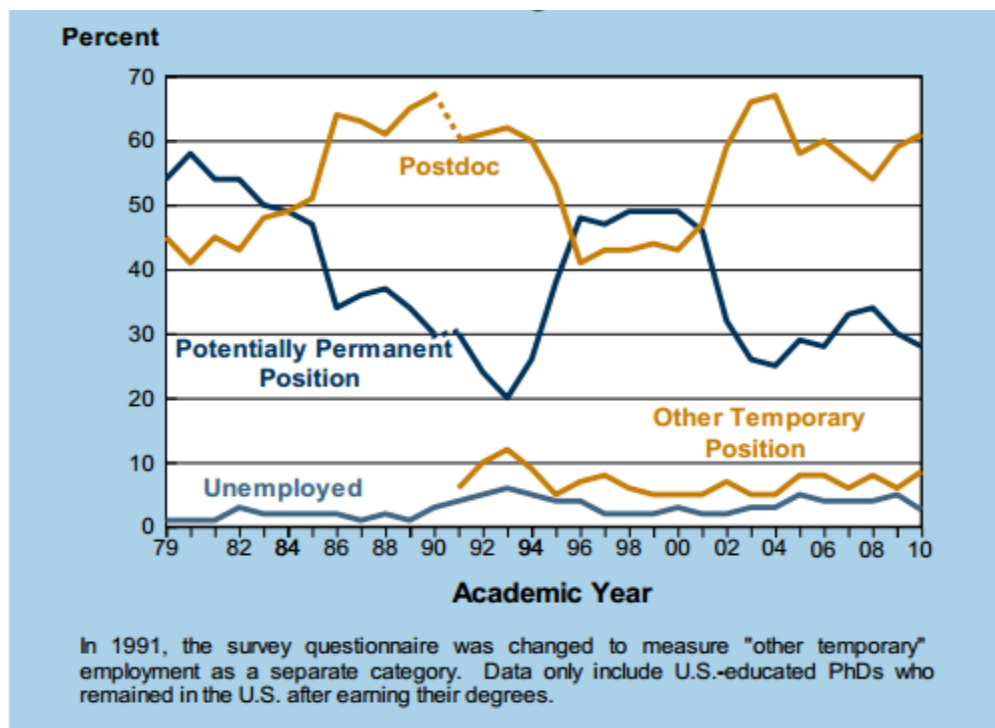


Figure 2. Initial employment of physics PhDs in the United States, 1979 through 2010. Source: (Anderson and Mulvey 2013)

<sup>12</sup> IT Company A.

### 5.3.3 Spatial Differences

There are also geographic differences in the labor markets for STEM workers. For example, software developers are in much higher demand in California, Washington state, and New York, which is reflected in their higher wages (see Figure 3). This trend is seen across different STEM occupations, and areas of demand vary. Petroleum engineers, for example, are clustered in Texas and Oklahoma. A recruiter for a company located in Connecticut told us that one of the primary challenges in hiring software developers is the location of the office, because many qualified candidates were reluctant to relocate to Connecticut.<sup>13</sup> Another recruiter mentioned that the company relocated to the Boston area specifically to gain access to the local talent pool, which improved recruitment.<sup>14</sup>

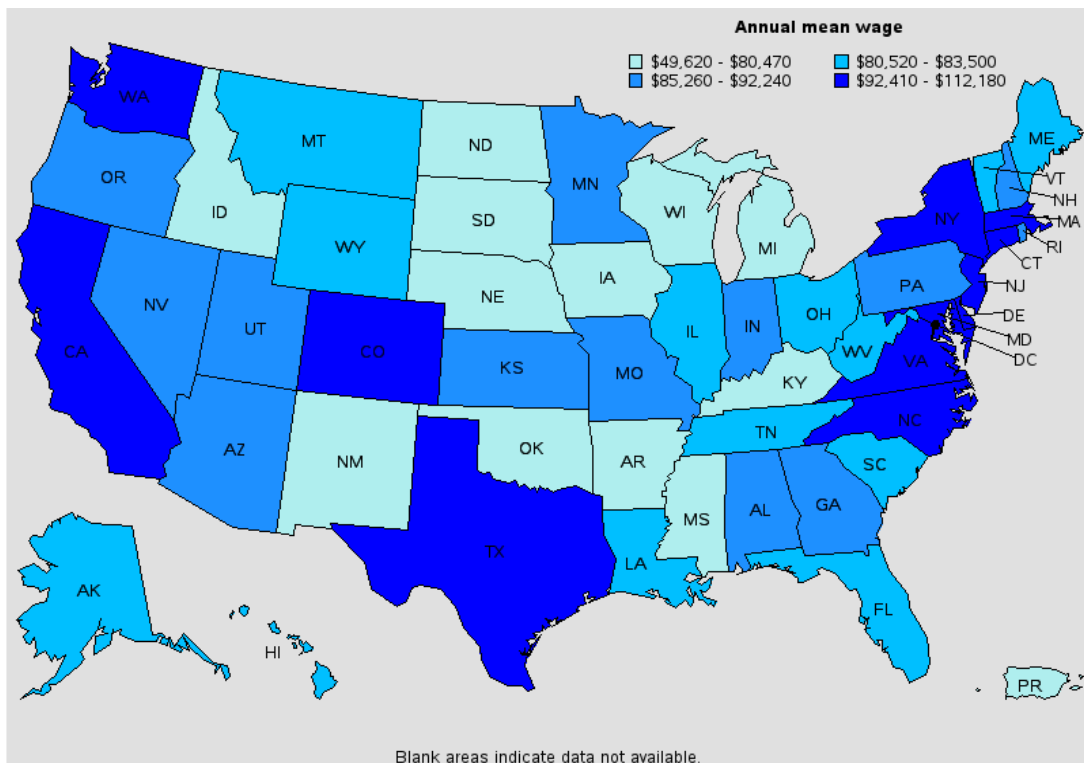


Figure 3. Annual mean wage of software developers, applications, by state, May 2013. Source: (Bureau of Labor Statistics 2013)

### 5.4 Summary

Across all the different disciplines, yes, there is a STEM crisis and no, there is not a STEM crisis. It depends on how and where you look.

For most PhDs, the United States has a surplus, especially for tenure-track positions in academia. The exceptions are certain fields within industry such as petroleum engineering, process engineering, and computer engineering, or nuclear engineering, materials science, and thermohydraulic engineering within the government space. Academia tends to absorb the PhDs unable to find positions in industry into postdoc positions. At the bachelor's and master's levels, there is consistent demand for employees

<sup>13</sup> Media Company A.

<sup>14</sup> IT Company E.

in software development, as well as in high-growth areas such as mobile app development, data science, and petroleum engineering. There is also demand below the bachelor's level, as the manufacturing industry requires workers in the skilled trades, such as machinists and technicians. Hence, we have a *heterogeneous* mixture of supply and demand for different occupations: some have a queue of workers, while some have a queue of unfilled positions.

Our findings are supported by the National Center for Education Statistics' longitudinal study of baccalaureate holders (Cataldi et al. 2014), which found that graduates who had not enrolled in advanced degree studies after they completed their bachelor's degrees in the 2007–08 academic year were employed 84 percent of the time on average and had a full-time annualized median salary of \$46,000 between graduation and 2012. For STEM majors, the percentage of time employed increased to 87.5 percent, and the full-time median salary was \$60,000. However, not all STEM majors were equally in demand. Computer and information sciences and engineering and engineering technology majors had median salaries of \$66,000 and \$67,000, respectively. Graduates who majored in biological and physical sciences, science technology, mathematics, and agricultural sciences had a median salary of only \$46,800, which was comparable to non-STEM majors. These data are consistent with our conclusion that there is significant variation in the demand for graduates depending on the STEM discipline.

## 6 Policy Discussion

STEM professionals span hundreds of occupations, with varying requirements for degree level and citizenship. Broad claims that there is an impending shortage of STEM professionals can be misleading given that certain STEM job segments are currently oversupplied. At the same time, our analysis shows many areas in which there is a clear demand for STEM professionals, such as software developers, petroleum engineers, and PhDs in certain engineering fields that require U.S. citizenship.

Although the majority of STEM bachelor's degree holders are not employed in STEM occupations (U.S. Census Bureau 2014), the acquired STEM skillset is widely applicable. STEM can be regarded, in a broader sense, as a way of thinking and doing rather than a set of occupations. Much as traditional literacy encompasses an ability to identify, understand, and communicate with written materials, "STEM-literacy" can be thought of as a set of core cognitive competencies such as logical reasoning, analytical thinking, and problem-solving skills. STEM education does not necessarily apply only to only who plan to pursue careers as scientists and engineers; competency in STEM can be for everyone (Larson 2014). We find that STEM graduates are hired not only into STEM-specific roles, but also in areas traditionally considered outside of STEM such as consulting, investment banking, and law. This corroborates with the findings of the Georgetown Center for Education and Workforce's Report on STEM, which suggest that the knowledge and skills acquired from a STEM background are not only applicable to traditional STEM domains but are widely sought after in other occupations as well (Carnevale, Smith, and Melton 2011).

As technology continues to advance and permeate our workplaces, the positions and job requirements for workers will continue to change. For example, modern automobiles

have evolved to be extremely complex systems: even a low-end vehicle is equipped with 30 to 50 electronic control units that execute software code and control everything from the stereo volume to air bags (Charette 2009). As a result, automotive master mechanics need to use computerized devices and must have an understanding of these systems. This shift towards highly skilled technicians with STEM knowledge is occurring across the manufacturing and construction industry (Rothwell 2013). The Brookings Institution found that around 13 million U.S. jobs available to workers without a four-year college degree require a high level of knowledge in at least one STEM field (Rothwell 2013).

To meet the demand for more STEM skills, policies are required to attract more students to acquiring STEM knowledge. Top-down policies need to be focused on specific areas of demand to address the shortage concerns as well as to avoid exacerbating oversupply in areas where there currently is no shortage (see

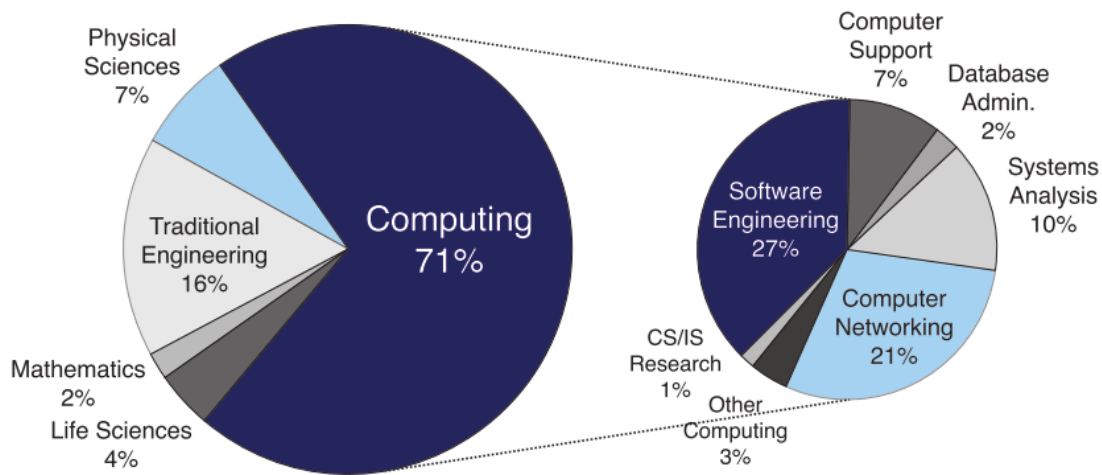


Figure 4 for projected areas of growth). Also, policies need to provide incentives to attract students to STEM. For example, the New York State STEM Incentive Program provides college scholarships to top-performing high school seniors who pursue a career in any STEM field (Chapman 2014). A bottom-up approach to bridging the gap is to have companies identify areas of need and sponsor students and/or employees for higher education. Companies such as Boeing and government agencies such as DOD have created specific programs that sponsor employees for higher education to address deficiencies in their pipelines of STEM workers. This has proven to be an effective mechanism to draw talent that pertains specifically to the needs of the employer.

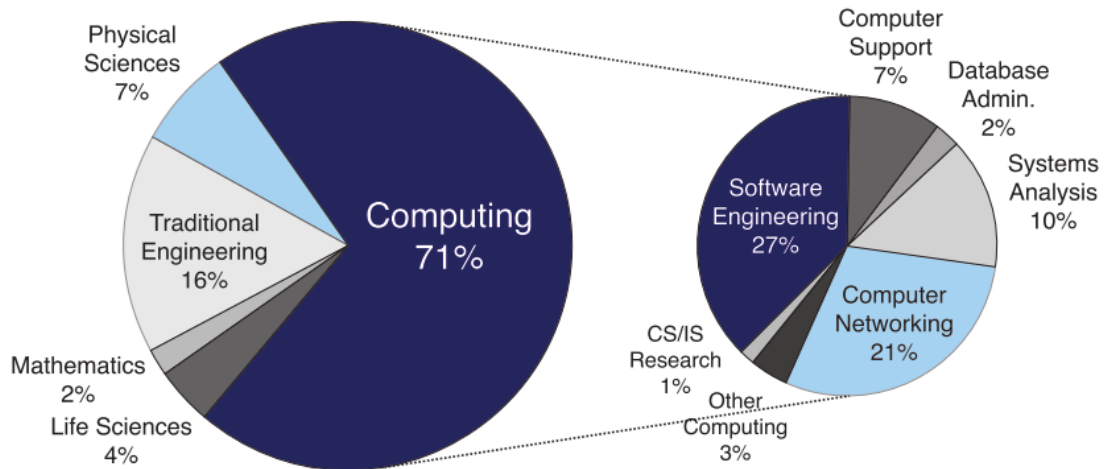


Figure 4. Projected New Jobs in STEM Occupations, 2008-2018. Source: (Munce and Fraser 2013) based on BLS data

## 7 Conclusion

This paper draws upon a variety of data sources – such as professional science and engineering societies, labor market data, the National Science Foundation, literature reviews, and anecdotal accounts – to understand the supply and demand landscape for the STEM labor market. It presents a first cut at identifying disciplines and degree levels that are in demand or oversupplied. A clearer picture of the supply and demand of the STEM workforce will require better data and consistent monitoring of both employer requirements and STEM worker availability.

We introduced the taxicab queueing model as a metaphor for the STEM labor market. Depending on the STEM job segment, we can either have a queue of positions waiting to be filled (cf. taxis) or we can have a queue of STEM workers waiting for jobs (cf. passengers). The characteristics of the queue depend on different factors: rate of job turnover (cf. taxi service rate); STEM worker arrival rate (cf. passenger arrival rate); number of positions available (cf. taxis in the fleet); location; degree level (cf. type of taxi); and citizenship. The model also highlights the probabilistic nature of the supply and demand market. Random fluctuations can cause job segments that traditionally have a shortage of workers to have a surplus, and *vice versa*. While we currently lack the data to operationalize the model, it presents a novel approach to characterizing the variation across STEM job segments.

Our central question is whether there is a “STEM Crisis” or a “STEM Surplus.” The answer is that both exist. From our analysis, we find:

- The STEM labor market is very heterogeneous. There are both shortages and surpluses of STEM workers depending on the particular job market segment.
- In the academic job market, there is no noticeable shortage in any discipline. In fact, there are signs of oversupply in many disciplines (e.g., biomedical sciences, physical sciences) for tenure-track faculty positions.

- In the government job sector, there are shortages for certain STEM disciplines at the PhD level (e.g., materials science engineering, nuclear engineering) and in general (e.g., systems engineers, cybersecurity, and intelligence professionals) due to the U.S. citizenship requirement. Oversupply can be seen in biomedical engineers at the PhD level, and there are transient shortages of electrical engineers and mechanical engineers.
- In the private sector, there is high demand for software developers, petroleum engineers, data scientists, skilled trades; an abundant supply of biomedical, chemistry, and physics PhDs; and transient shortages/surpluses of electrical engineers.
- Location of the position affects hiring ease or difficulty.

Policies that try to solve shortages by increasing overall supply of STEM graduates through attracting students or increasing federal funding may not improve the overall STEM workforce, and may even exacerbate any mismatches between supply and demand. As our society relies further on technology for economic development and prosperity, the vitality of the STEM workforce will continue to be a cause for concern.

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