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Preparing for the 21st Century Biomedical Research Job Market: Using Census Data to Inform Policy and Career Decision-Making
Version 1

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Abstract The U.S. biomedical scientific enterprise has a long, deep history of innovation, global leadership, and scientific advancements that have improved the health and wellbeing of humankind. Biomedical scientific careers ebb and flow with funding availability, and funding drives this workforce in terms of size and structure. The stakes are high for becoming a scientist because large amounts of time and capital investments are required to be competitive in this profession and because the labor market is heavily dependent on the availability of external funding. Ideally, students and postdocs will make career decisions based on market data regarding the potential for future advancement and career expectations.

Young scientists are struggling today more than they ever have in finding productive tenure-track academic employment. The landscape has drastically changed as numerous young scientists take jobs in industry and government, some of them choosing these jobs over academia. We hope this paper, told with historical census data, empowers early career scientists and the senior investigators who mentor them with information about today's labor market that they can use to help young scientists make informed decisions about their career paths.

Thoughts, opinions, and any errors are solely those of the authors and do not necessarily reflect the views of the US Census Bureau or National Institutes of Health.

Abbreviations

NIH: National Institute(s) of Health; PI: Principal Investigator; RPG: Research Project Grant; HR: Human Resources; NSF: National Science Foundation; SED: Survey of Earned Doctorates; SDR: Survey of Doctorate Recipients; GSS: Survey of Graduate Students and Postdoctorates in Science and Engineering; HERD: Higher Education Research and Development Survey; NPA: National Postdoctoral Association; ACS: American Community Survey; URM: Underrepresented Minority; GRE: Graduate Research Education General Test; NRMN: National Research Mentoring Network; IPUMS: Integrated Public-Use Microdata Series; GDP: Gross Domestic Product; BRDPI: Biomedical Research and Development Price Index

Introduction

At the 2015 Boston Future of Research (FoR) Symposium, economist and keynote speaker Paula Stephan described the economic forces that govern trends in the academic labor market, providing a valuable economic perspective on a debate that has been informed mostly by personal experience in the biomedical research community. A major topic of discussion was the lack of data on the biomedical workforce in the United States, particularly the absence of data about the postdoc workforce, and the potential viability of alternative data sources to provide young scientists with information to inform their career decisions. In this context, NIH labor economist Misty Heggeness provided historical data from the U.S. Census Bureau.

We present it in this commentary for all young scientists to access. While much has been written discussing the general history and state of the scientific and engineering workforce in the U.S. Alberts et al. [2014], Stephan [2012], Teitelbaum [2014], what we present here is, to our knowledge, the first detailed overview of a specific perspective on the specialized history of the U.S. biomedical workforce from its inception to today using census data. We show, through data, how the characteristics of this workforce today are like nothing we have seen in history. Using census data Ruggles et al. [2015], we hope to inform and guide the often-anecdotal discussions about academic reform.[1]

[1] Detailed information regarding educational attainment for PhDs does not exist in the census data until 1990. Given this limitation, we provide an overview of all individuals identified as medical or biological scientists up to 1960 regardless of educational attainment. From 1960 to 1990, we estimate characteristics of a workforce with 5 or more years of university education, and from 1990 to the present, we discuss the labor market for PhDs only. A proportion of biomedical researchers does not have a PhD but instead has an MD or similar professional degree. Because of this, we present the data on individuals from 1990 to the present who have received a PhD, MD, or equivalent professional degree in Supplemental Figure 5.

History of NIH Funding and the Growth of a U.S. Biomedical Research Workforce

The National Institutes of Health (NIH) has been the primary federal funder of biomedical research in the U.S. since the 1930s. Consequently, fluctuations in the NIH budget, along with increases in both foundation and private sector funding of biomedical research in recent years, have influenced the size and demographics of the workforce. In this section, we describe the birth and growth of NIH funding and the U.S. biomedical workforce.

The Advent of the NIH and the Federally-Funded Biomedical Workforce

The U.S. biomedical workforce traces its roots back to the late 1700s, with the establishment of the Marine Hospital Service in 1798 National Institutes of Health [2016c]. The earliest available data on biomedical scientists comes from the U.S. Decennial Census of 1850, in which fewer than 100 individuals were identified as biological or medical scientists (Supplemental Figure 1). By 1880, the number doubled to around 200 and, by the turn of the century and the establishment of the Hygienic Laboratory Advisory Board in 1902, around 500 individuals in the United States had occupations as biological or medical scientists. The biomedical workforce grew rapidly in the early 20th century, increasing by 60.2% to over 800 research scientists by 1910 and increasing over 200% to approximately 2,500 research scientists by 1920 (Supplemental Figure 1).

As the Great Depression hit and post-World War I advancements in research came about, what we now know today as the NIH came into existence as the "National Institute of Health" via the Ransdell Act of 1930. The Act "changed the name of the Hygienic Laboratory to National Institute (singular) of Health (NIH) and authorized the establishment of fellowships for research into basic biological and medical problems" National Institutes of Health [2016c]. No more than 4,000 individuals were employed as biological and medical scientists in the U.S. at the time (Supplemental Figure 1), but it probably was not coincidence that an exponential growth of scientists occurred in the years leading up to the formal establishment of the NIH.

The Golden Years of the NIH Expansion (the "Great Expansion")

In 1946, a phase called the "Golden Years of NIH Expansion" or the "Great Expansion" began and lasted until 1966. During this time, funding was in effect unlimited and proposals were almost guaranteed to

be financed National Institutes of Health [2016c]. The NIH budget increased from less than 500 million U.S. dollars in 1946 to over 5 billion U.S. dollars by 1966 [inflation adjusted using the GDP Price Index for 2009 dollars] (Figure 1A), a more than ten-fold increase that took place over 20 years. As the budget grew exponentially, so did the number of scientists working in the United States (Figure 1B). By 1960, around 30,000 individuals were working as biological or medical scientists in the U.S. There was an increase in the number of biomedical scientists acquiring higher education: the number of scientists with five or more years of university education increased from 2,279 in 1950 to 20,520 by 1960 (Figure 1B).

Slow and Steady Late-Century Growth of a Biomedical Research Workforce

The biomedical workforce has historically experienced trends that oscillate between an over and under supply of labor and this has been documented in the literature as early as the 1960s (Supplemental Figure 2). In the late 1960s, Congress required more discretion in the type of research funded, and more formal processes were put into place for the review and distribution of research funding National Institutes of Health [2016c]. While the number of biomedical scientists in the workforce continued to increase, the structure of funding changed dramatically. By 1970, post the Great Expansion, the number of scientists in the labor market was still increasing, and there were almost 60,000 scientists with 5 or more years of university education working in the U.S. (Figure 1B). As the NIH budget began to flatten, so did the number of university-educated scientists working in the United States following a lag period. Two decades after Congress tightened restrictions on the allocation of NIH-funded science in the 1960s, the NIH budget (inflation-adjusted) again decreased slightly in the early 1980s. By 1990, a lagged effect of decreased investments over time, among other factors, resulted in the number of biomedical scientists with more than five years of university education working in the labor market decreasing from 71,700 in 1980 to 67,248 in 1990, a 6.2% reduction in the workforce (Figure 1).

A Call for Investment, and the Abolition of Mandatory Retirement in Universities

During the 1980s, papers and commentaries increasingly spoke about the "dire straits" of science: the need to increase investments and training so as not to face a brain-power shortage or crisis (Bickel and Morgan [1980], Healy [1988], Supplemental Figure 2). During the late 1990s, the challenging environment for new PhD scientists Freeman [1999] and the problems recent graduates were having in finding jobs were topics for discussion, similar to those we observe currently about scientific (particularly biomedical) research.

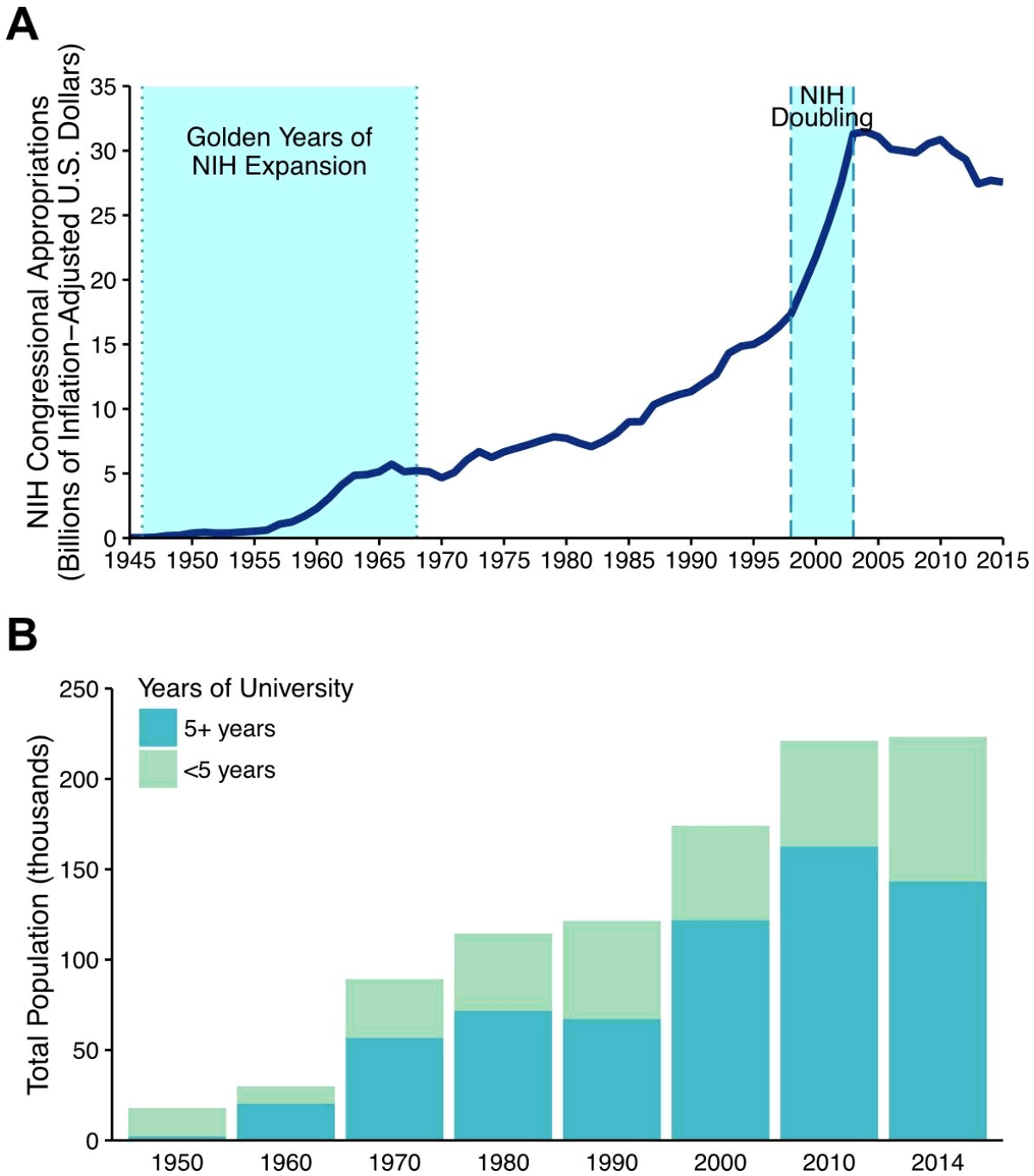

Figure 1: Growth of the U.S. biomedical workforce, 1950-2014.

The number of biological and medical scientists, as defined by occupation, has increased dramatically in the last half century. A. Congressional appropriations (inflation-adjusted using the GDP Price Index), 1945-2015. B. All biological and medical scientists in the U.S. and those with 5 or more years of university education, 1950-2014. Sources: NIH Office of Budget (https://www.nih.gov/about-nih/what-we-do/nih-almanac/appropriations-section-2) and authors' calculations, IPUMS-USA decennial census and ACS 1% files (https://www.ipums.org/).

Coincidentally, in 1995, mandatory retirement policies at universities became illegal, preventing universities from requiring faculty to retire at age 65 Ashenfelter and Card [2002], Taylor [2010]. In addition to ongoing interest in their work, many professors continued working, for multiple motives, including to potentially offset drops in their retirement savings that occurred during U.S. stock market crashes in 1997 and 2000 and because, as the NIH doubling began (discussed in detail below), research funding increased, making it easier to obtain, especially for seasoned scientists. The predicted Ashenfelter and Card [2002] increase in established independent researchers had the direct effect of reducing the number of open positions for younger scientists trying to enter into the academic labor market precisely following a decade of concerns about training enough young scientists for future research.

The "NIH Doubling"

The public policies of the 1990s dramatically influenced the current structure of the biomedical workforce. In addition to the effects of abolition of mandatory retirement at universities, 1998 marked the beginning of the "NIH Doubling", a five-year period (1998-2003) during which the NIH budget for scientific research increased almost two-fold (Figure 1A). It had great and lasting impacts on the speed and ability of the United States to continue engaging in cutting-edge research Zerhouni [2003].

This rapid expansion created great short-term opportunities for conducting research. The number of research project grants (RPGs) increased from 7,389 in 1997 to 10,393 in 2003, a 40.7% increase in the number of projects funded (Supplemental Figure 3A), and the number of R01-equivalent grants increased by 32.7%, from 5,378 grants in 1997 to 7,255 grants in 2003 (National Institutes of Health [2016a], Supplemental Figure 3B). During an equivalent period, the number of R01-equivalent PIs increased by 19.1%, from 5,797 in 1998 to 6,905 in 2003 National Institutes of Health [2016b]. Not only were more projects and researchers funded, the average amount of funding they were receiving also increased. The average cost of an R01-equivalent grant increased from 446,186 U.S. dollars in 1997 to 482,296 U.S. dollars in 2003 (BRDPI inflation-adjusted, 2015 dollars), an increase after inflation of about 8.1% National Institutes of Health [2016b]. Because of the increase in available research funding, the number of trainees funded by the NIH increased exponentially, creating a cohort of "Doubling Boomers" within biomedical science National Institutes of Health [2015].

The "Doubling Boomers" Enter the Workforce

The NIH Doubling had unintended consequences, one of which was that it indirectly influenced the number of students and postdocs trained in biomedical research. In order for scientists to increase their productivity with increased budgets and more funding, they needed more hands in the lab. In biomedical research, this comes in the form of students and postdoctoral researchers ("postdocs"). These students and postdocs – the "Doubling Boomers" – have in recent years been flooding the labor market looking for steady, stable jobs as research scientists.

Individuals who began their training under the umbrella of the NIH Doubling would have started their graduate training between 1998 and 2008 (assuming grants last, on average, five years). It takes the average biomedical graduate student 6 to 7 years to complete their program Biomedical Research Workforce Working Group [2012]. Those who go on to do a postdoc are in a postdoctoral position for an average of five years Biomedical Research Workforce Working Group [2012]. This implies that the first cohorts of Doubling trainees entered the labor market in postdoctoral positions (or other permanent employment positions if they did not pursue a postdoc) as early as 2004.

The Doubling Boomers can be seen in nationally representative survey data. The number of new biomedical PhD entrants into the job market doubled from around 5,000 per year to 10,000 per year between 1988 and 2008 (Figure 2A). In 2007, there were 61,543 PhDs, 38,178 of them under age 45, working as biological or medical scientists (Table 1, Figure 2B). By 2011, there were 47,168 under age 45, a 23.5% growth in the number of PhD scientists under 45 in the labor force (Table 1, Figure 2B). For the entire population of biomedical scientists of all ages, the number grew to 81,259 in 2011, a 32.0% growth. Therefore, of the additional ∼20,000 workers between the first and second period, ∼9,000 of them were under age 45: 45.6% of the growth in new workers was due to those under the age of 45. These are the Doubling Boomers.

As these new trainees entered the workforce, retirement (i.e. those exiting) slowed, so competition has steadily increased for new entrants into the academic scientific labor market. This has been exacerbated by universities' increasing reliance on full- and part-time non-tenure track faculty, instead of the more expensive tenure-track faculty (Figure 1 in Curtis and Thornton [2013]). Even during the NIH Doubling, there was no increase in the number of tenure-track biomedical faculty under age 55, although there was a modest increase in the number of tenure-track faculty over age 55 (Figure 2 in Stephan [2008]). In the late 1960s, over 55% of biological science PhDs landed a tenure-track faculty position within five to six years of receiving their degrees. This number has decreased sharply over time to 32% in the early 1980s

Age Group	<45		45-54		55-64		65+		Total Population	
	N	s.e.	N	s.e.	N	s.e.	N	s.e.	N	s.e.
Year										
2002	35,021	(187)	14,126	(119)	3,507	(59)	2,477	(50)	55,131	(235)
2003	37,726	(194)	14,006	(118)	7,642	(87)	4,301	(66)	63,675	(252)
2004	34,405	(185)	15,983	(126)	6,021	(78)	2,173	(47)	58,582	(242)
2005	40,780	(202)	14,616	(121)	7,873	(89)	2,555	(51)	65,824	(257)
2006	39,186	(198)	16,667	(129)	7,696	(88)	3,093	(56)	66,642	(258)
2007	38,178	(195)	12,538	(112)	8,447	(92)	2,380	(49)	61,543	(248)
2008	39,440	(199)	13,198	(115)	9,296	(96)	3,252	(57)	65,186	(255)
2009	40,166	(200)	14,671	(121)	9,886	(99)	4,287	(65)	69,010	(263)
2010	45,721	(214)	16,703	(129)	9,448	(97)	5,065	(71)	76,937	(277)
2011	47,168	(217)	18,571	(136)	11,541	(107)	3,979	(63)	81,259	(285)
2012	44,360	(211)	16,800	(130)	11,276	(106)	5,858	(77)	78,294	(280)
2013	41,230	(203)	15,549	(125)	12,385	(111)	5,293	(73)	74,457	(273)
2014	42,063	(205)	14,582	(121)	8,057	(90)	4,588	(68)	69,290	(263)

Table 1: Age Distribution of Biological and Medical Scientists with PhDs, United States, 2002 to 2014 Source: Authors' calculations, IPUMS ACS 1% files (https://www.ipums.org/).

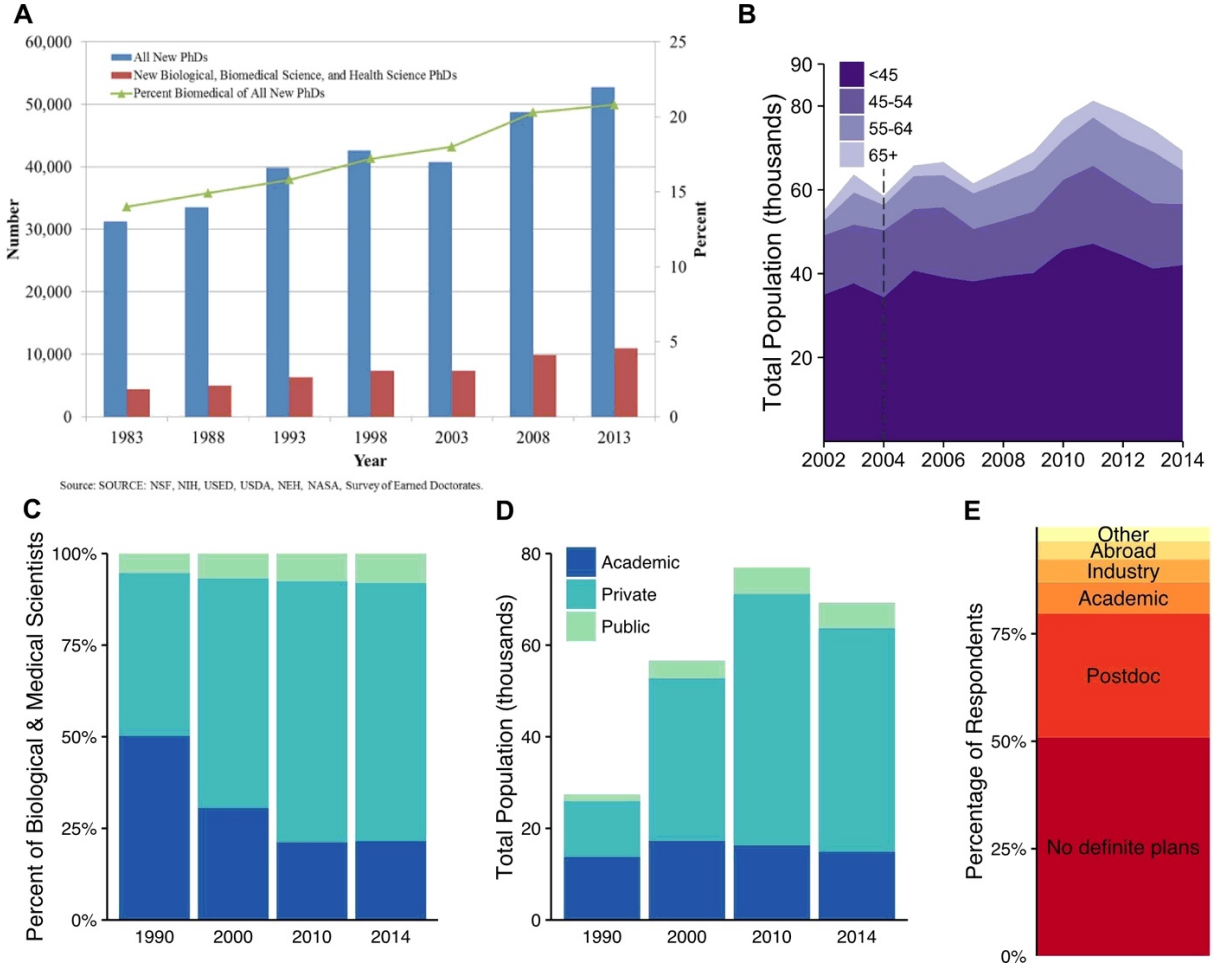

Figure 2: The U.S. PhD biomedical workforce by age and industry, 1983-2014.

A. The number of new PhDs, new biomedical PhDs, and the percent of new PhDs that are biomedical, 1983 to 2013. B. Number of PhDs working as biological or medical scientists, by age. The Doubling Boomers enter the workforce. The first wave of Doubling Boomers began receiving their PhDs in 2004 (dashed line). C. & D. Industry composition (academic, dark blue; private, light blue; or public, light green) of biological and medical PhD scientists by year, as a percentage of the biomedical workforce (C) and total population (D). E. Post-graduation employment plans of biomedical PhD recipients, 2014. Sources: Panel A uses data from the National Science Foundation (NSF) Survey of Earned Doctorates (SED). Panels B-D are authors' calculations from the IPUMS decennial census and ACS 1-year files (https://www.ipums.org/). Panel E uses data from the 2015 NSF SED.

and to less than 15% by 2006 Stephan [2012].

With limited opportunities in academic and research institutions, individuals flow into the private sector or government Polka [2014a], linger in postdoctoral positions, or exit out of science entirely. Biological and medical scientists in academia made up around 50% of all biological and medical science jobs held by PhD scientists in 1990, but less than 25% by 2010 (Figure 2C). While the total number of jobs in academia for biological and medical scientists has remained relatively flat, the number of biomedical scientists working in private industry and government employment has increased fourfold between 1990 and 2014 (Figure 2D). Additionally, new PhDs experience uncertainty when they finish their degree and enter the labor market. In 2015, more than half (50.9%) of new PhD recipients had no concrete plans for future employment around the time they received their degrees (National Science Foundation [a] Figure 2E).

Post-Doubling Funding

Since 2003, the NIH budget has steadily eroded, creating strain on the system and more competition for faculty positions and grant funding opportunities Trivedi [2006]. Between 2003 and 2014, the NIH budget fell from $39.1B to $30.8B (BRDPI inflation-adjusted, 2015 dollars). In testimony to the U.S. Senate Subcommittee on Labor, Health and Human Services, Education, and Related Agencies, Dr. Francis Collins said of the Fiscal Year 2016 budget request, "the NIH has lost approximately 22 percent of its purchasing power for research since 2003, and the likelihood that a grant applicant will achieve funding after peer review has fallen to the lowest in decades, now less than 20 percent" Collins [2015]. After adjusting for inflation, the NIH budget can only support around 4 out of every 5 projects that were funded in 2003.

The NIH Doubling ended in 2003. However, just as with the Great Expansion, the supply chain response lagged behind the decrease in post-Doubling funding, and the number of scientists entering the labor market post-Doubling continued to grow years after the NIH Doubling ended. By 2010, there were more than 220,000 individuals working as biological or medical scientists in the U.S., 160,000 of them with 5 or more years of university education and over 75,000 of them PhD scientists, compared to only 120,000 in 1990, less than 30,000 of them PhD scientists (Figure 1B, Supplemental Figure 3C). Therefore, between 1990 and 2010 there was a 180% increase in the number of PhDs working as biological or medical scientists in the U.S.

An Aging Academic Workforce

Although the number of young PhD scientists entering the workforce has increased dramatically in recent years, the NIH-funded academic workforce is aging. The average age of receiving one's first independent NIH award has crept up from 36 years old in 1980 to 42 years old in 2011 Rockey [2012a]. The age dynamics of the workforce can be estimated by looking at the ratio of younger workers to older workers. Researchers have created a Retirement-Age Dependency Ratio, or Principal Investigator (PI) Replacement Index Heggeness et al. [2016a], showing the rate of growth that would be required in the number of independent PIs under a certain age to maintain current research funding and output in the absence of PIs above that age. While the NIH 65-year old PI Replacement Index was 2.1% in both 1980 and 1990, by 2000, five years after mandatory retirement at universities was eliminated, it had doubled to 4.2% and has continued to grow Heggeness et al. [2016a]. In 2014, if all PIs aged 65 and older were to retire, the number of PIs under age 65 would need to increase by 10.2% to maintain the total number of PIs; if those over 70 retired, the number of younger PIs would need to increase by 3.7%. The number of NIH applicants and awardees over age 65 has also increased in recent years (Supplemental Figure 4; see also institution-specific data in Heggeness et al. [2016a], Charette et al. [2016]). Together, these data point to a workforce that, following the abolition of mandatory retirement, includes those above retirement ages in larger proportions than ever before.

The Demographics of the Labor Market

Through historical census data, we have some appreciation of the demographics of the biological and medical science labor market. This next section shows dramatic changes in the composition of the workforce over time. While we must continue to strive to diversify the workforce, the biomedical workforce is more diverse today than at any other point in history, as these data show.

Race, Ethnicity, and the Workforce

Fostering a diverse and inclusive scientific enterprise is essential to allowing talent from all sections of the population to thrive National Academies [2011b], and directly benefits scientific research Freeman and Huang [2014], Joshi and Roh [2009].

The U.S. biomedical workforce is more racially diverse now than ever before. In 1990, less than 15% of PhD biomedical scientists were non-White (Table 2, Figure 3A). By 2014, 41.5% were non-White (Table 2, Figure 3A). At least some of the diversification of the biomedical workforce is likely due to the decreasing number of white U.S. citizen men completing PhDs in science and engineering and the increased internationalization of the workforce. The total number of PhDs awarded has increased dramatically during this period, and these increases are made up of non-citizens, citizen women, and men of color Stephan [2012].

Underrepresented minorities (URMs), "individuals from racial and ethnic groups shown to be underrepresented nationally National Science Foundation, National Center for Science and Engineering Statistics. [2015] defined as Blacks or African Americans, Hispanics or Latinos, American Indians or Alaska Natives, Native Hawaiians and other Pacific Islanders" National Institute of General Medical Sciences [2016], are overrepresented in NIH training programs, but many of these groups are still underrepresented in NIH Research Project Grants (RPG) and R01-equivalent funding Heggeness et al. [2016b]. It is an open question whether this will continue to improve on its own over time as more diverse young cohorts age or whether it requires a direct policy intervention Zeng [2016], Zeng and Heggeness [2016]. Preliminary evidence suggests, for example, that while we can expect the percentage of NIH RPG funding recipients who are women to increase by 4-6% points to around 39% by 2027 given today's cohorts, policy intervention is probably be necessary to bring women to equal representation with men Zeng [2016], Zeng and Heggeness [2016]. Similarly, a recent study has suggested that while white women are as likely to receive NIH R01 grant funding as white men, Asian and black women are less likely to receive funding than their white counterparts, and for black women the factor of race is posited as the greatest source of

Year	1990		2000		2010		2014	
	N	s.e.	N	s.e.	N	s.e.	N	s.e.
Total Population	27,425	(166)	56,643	(238)	76,937	(277)	69,290	(263)
Sex								
Male	18,562	(136)	35,949	(190)	43,395	(208)	40,895	(202)
Female	8,863	(94)	20,694	(144)	33,542	(183)	28,395	(169)
Citizenship Status								
Citizen	21,432	(146)	30,118	(174)	37,324	(193)	33,624	(183)
Naturalized	2,222	(47)	6,815	(83)	10,904	(104)	12,411	(111)
Non-Citizens	3,771	(61)	19,710	(140)	28,709	(169)	23,255	(152)
Race								
White, non-Hispanic	23,406	(153)	36,558	(191)	44,315	(211)	40,554	(201)
Black, non-Hispanic	311	(18)	1,272	(36)	2,610	(51)	1,106	(33)
Asian, non-Hispanic	3,326	(58)	16,889	(130)	25,301	(159)	23,381	(153)
Other, including Hispanic	382	(20)	1,924	(44)	4,711	(69)	4,249	(65)
Industry								
Private	12,172	(110)	35,477	(188)	54,827	(234)	48,790	(221)
Academic	13,794	(117)	17,326	(132)	16,336	(128)	14,932	(122)
Public	1,459	(38)	3,840	(62)	5,774	(76)	5,568	(75)

Table 2: Descriptive Statistics of Biological and Medical Scientists with a PhD, United States, 1990 to 2014 Source: Author's calculations, IPUMS decennial censuses, IPUMS ACS 2010 and IPUMS ACS 2014 (https://www.ipums.org/).

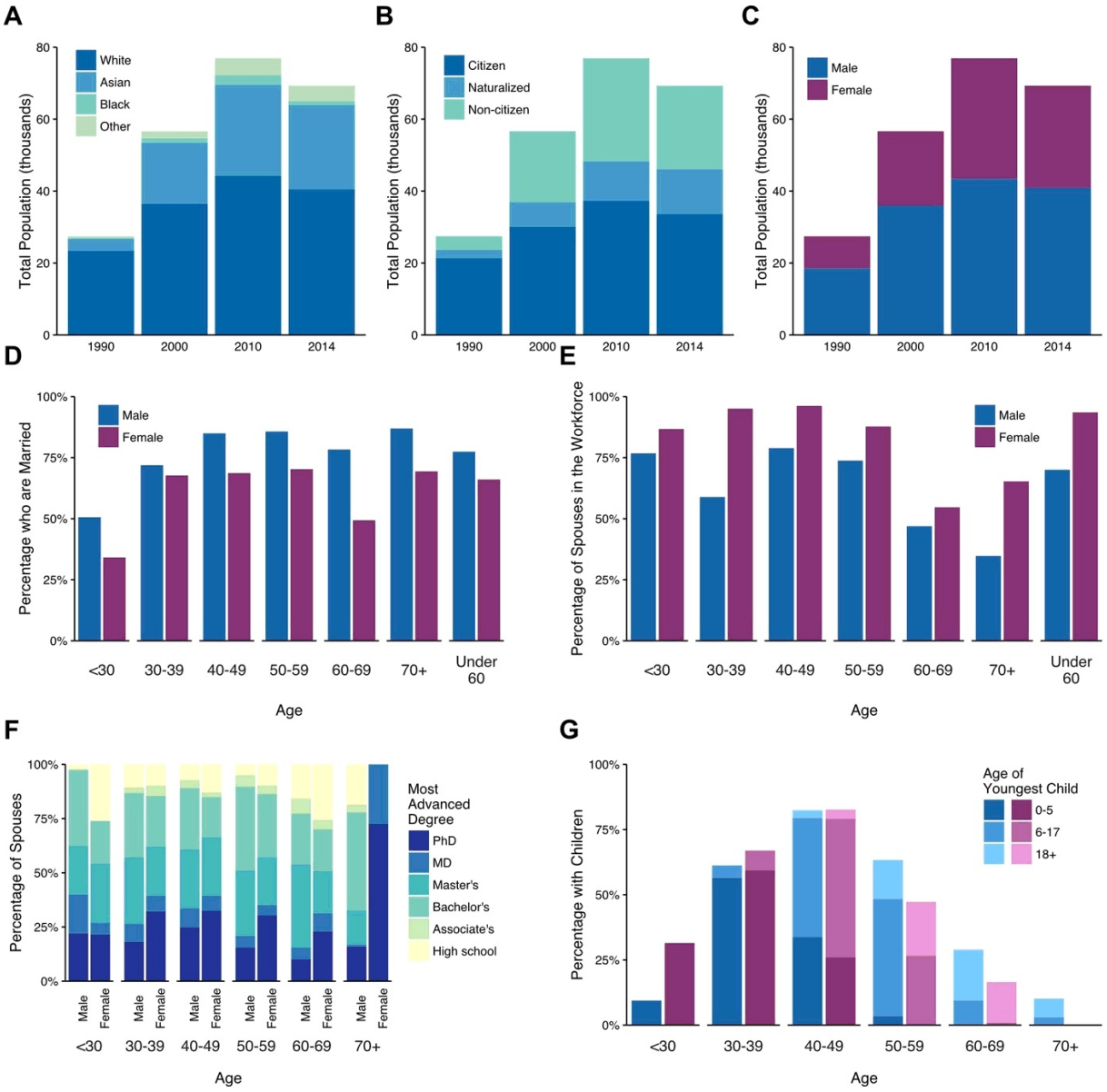

Figure 3: The changing face of the American biomedical PhD workforce, 1990-2014.

A. The biomedical workforce has become more racially diverse over time. Population of the U.S. biomedical workforce by race. B. Non-citizens and naturalized citizens make up an increasingly large proportion of the U.S. biomedical workforce. C. The proportion of women in the biomedical science workforce has increased over time. D. Percentage of biomedical scientists who are married, by scientists' age and gender, pooled 2012-2014. E. Labor force status of biomedical scientists' spouses, by scientists' age and gender, pooled 2012-2014 shows that female biomedical scientists have a higher rate of working spouse. F. Educational attainment of biomedical scientists' spouses, by scientists' age and gender (pooled 2012-2014) shows that women have higher rates of a spouse with a PhD or professional degree than men. G. Percent of married biomedical scientists with children, by scientists' age and gender, pooled 2012-2014. Source: Panels A-C are authors' calculations from IPUMS decennial census data 1% files (1990-2010) and IPUMS ACS 1-year files (2014). Panels D-G are authors' calculations from the IPUMS ACS 1-year files (2012-2014, https://www.ipums.org/).

disparity Ginther et al. [2016]. Furthermore, modeling has suggested that at current postdoc-to-faculty transition rates, faculty diversity would not increase significantly (even with a dramatic increase in the trainee URM population) until 2080 Gibbs et al. [2016].

When looking at the distribution of URMs in the academic career trajectory, it becomes clear that diversity decreases as scientists progress from graduate school to postdoc to faculty positions. Much effort has focused on the need to attract more URM students, but this is not translating into a representative population throughout the academic career path. In 2013, 58% of full-time professors were white men. Twenty-six percent were white women; and Black, Hispanic, American Indian/Alaska Native individuals and those of two or more races, all combined and of all genders, made up less than 7% of full-time professors Kena et al. [2016]. The attrition appears at each transition within the career pathway of academia Kena et al. [2016]. Recently Alberto Roca of Minority Postdoc (www.minoritypostdoc.org) identified data from the NSF GSS showing that in 2013, there were at least 3,083 URM postdocs, and 8,523 including Asian researchers, in a surveyed population of 61,942 Roca [2015]. Recent work by Gibbs et al. has further demonstrated that there is a viable pool of minority scientists available to increase diversity of the workforce, and that issues related to the identification of postdocs and their transition into the labor market, combined with hiring practices, are affecting translation of the diversity of the trainee population into a diverse faculty Gibbs et al. [2016]. Therefore there is work to be done improving diversity at all levels in science, particularly in faculty recruitment and retention, and not just recruiting and retaining diverse students.

Although many current efforts focus on attracting minority applicants to graduate programs, the problem seems less in attracting applications from a diverse background than actually admitting them to PhD programs, and supporting them throughout their academic careers. Recent scrutiny of graduate admissions demonstrates an overdependence on the Graduate Research Education (GRE) General Test and questions its ability to be used as a selection criterion Bell et al. [2014], Miller and Stassun [2014], Pacheco et al. [2015], Posselt [2016], Weiner [2014]. Focusing on race and gender differences in the interest in pursuing research careers shows that women, URMs, and, in particular, URM women are less likely to report high interest in faculty careers Gibbs et al. [2014]. These differences remain when accounting for factors such as relationships with advisors, publications, and confidence differences. Interventions must address the climate and culture of how we do science to lead to a more diverse and inclusive academic enterprise. In addition, reducing the impact of bias has been identified as a key target for policy interventions in diversification of the STEM workforce, a national priority Office of Science and Technology Policy [2016].

The values that drive scientists to pursue faculty careers differ across race/ethnicity and gender, and these values, coupled with structural dynamics of biomedical research, also influence who pursues and ultimately becomes a faculty member/independent researcher Gibbs and Griffin [2013], McMurtrie [2016a]. This, combined with a higher attrition rate from PhD programs for URM students Sowell et al. [2015], points to: 1) a need for greater investment in those within academia already Duncan et al. [2016]; 2) the importance of studying what support is lacking and ways to improve mentorship, with projects such as the National Mentoring Research Network (NRMN, www.nrmnet.org, McMurtrie [2016b], Pfund et al. [2015]); and 3) the necessity of addressing structural issues that have been identified as barriers to promoting to diversity and inclusion Gibbs and Griffin [2013].

It also highlights a need to shift from the harmful use of the "pipeline" descriptor for scientific training, as if a full time professorship at a research-intensive institution is the pinnacle of the scientific contribution an individual can make, and towards a "tributary" or "pathways" description as recommended by leaders in this field Cannady et al. [2014], Gibbs and Griffin [2013], McMurtrie [2016a], Valantine [2016].

The Internationalization of the Biomedical Research Workforce

The U.S. biomedical workforce has experienced a boom of non-citizens and become increasingly international in the past three decades. In 1990, 13.8% of the PhD scientific workforce was non-citizen (Figure 3B). By 2000, it more than doubled to 34.8%, and, in 2014, 33.6% of the workforce was non-citizen. Between 2010 and 2014, the only group of scientists that increased in number was naturalized citizens.

Postdocs are increasingly likely to be international (pages 166-167, Stephan [2012]): in 1980, around 40% of postdocs were temporary residents, and in 2008 this was estimated at around 60%. The National Postdoctoral Association's Institutional Policy Report Ferguson et al. [2014] also estimated the number to be somewhere over 60% in 2014. Analysis of the NSF GSS data suggested that in 2013, there were 32,396 postdocs on temporary visas in a surveyed population of 61,942, or 52%, across all fields Roca [2015]. Many postdocs receive their PhDs outside the U.S.: 50% of academic postdocs in the U.S. received their PhDs elsewhere and four out of five postdocs on a temporary visa received a PhD elsewhere Stephan [2012].

The fluidity with which PhD scientists move across borders is indeed a reality today. The movement of scientists internationally is complex: aspirational factors such as autonomy are posited to drive researchers to move to other countries Baruffaldi and Landoni [2016]; but there are also factors driving re-

searchers to return to their home countries, particularly if they maintain strong links with home Baruffaldi and Landoni [2012]. Complex relationships between awareness of labor markets/career options, personal aspirations and field of study also affect mobility Bloch et al. [2015]. The GlobSci Survey of more than 45,000 researchers in 16 countries in 2011 provided data showing the prominent role of the U.S. in global research Franzoni et al. [2015], illustrating the need for the U.S. research enterprise to study its role in in the international scientific arena. Increased data collection across borders, such as with the recent changes the National Science Foundation (NSF) is incorporating into the Survey of Doctoral Recipients (SDR) in order to follow individuals who were granted a PhD in the U.S. when they leave the country, is warranted so that we can better understand these global trends in the future National Science Foundation [b].

Women in Biomedical Science

Women's participation in the scientific enterprise facilitates economic development and spurs advancements in science Plank-Bazinet et al. [2016]. Women have made great strides in entering the biomedical workforce, even as they continue to face additional challenges compared to their male colleagues. The proportion of women in the biomedical science workforce has increased from 21.4% in 1960 to almost half in 2010 (Supplemental Figure 6C & F). In 1990, 30.1% of PhD scientists in the United States were female; by 2014, this number had risen to 43.3% (Table 2, Figure 3C). In spite of making up almost half the PhD biomedical workforce, numerous studies have highlighted the lack of women in leadership positions Eagly and Miller [2016], Ginther et al. [2016], Heggeness et al. [2016b], Jolliff et al. [2012], Mayer et al. [2014], Plank-Bazinet et al. [2016].

PhD women in biomedical science careers are more likely than their male colleagues to be balancing work, marriage, and a spouse with a career. From 2012-2014, an average of 66% of female scientists under age 60 were married (Figure 3D). Among those married scientists under age 60, 93.5% had a spouse in the workforce (Figure 3E). This compares to 70.0% of married men under age 60 with a working spouse (Figure 3E). Female scientists are less likely than their male counterparts to have a non-working spouse who can shoulder responsibilities at home (Figure 3E, Supplemental Figure 7).

More women are married to a spouse with a doctoral or professional degree compared to men. From 2012-2014, more than a third (38.5%) of married female biomedical scientists aged 30-39 had spouses with a PhD, MD, or equivalent, while only a quarter (26.0%) of married men aged 30-39 had a spouse with a PhD, MD, or equivalent (Figure 3F).

The push for independence and tenure comes at a time when many female scientists are balancing career and family, often including young children in the household. From 2012-2014, 67.7% of PhD female scientists aged 30 to 39 were married (Figure 3D). Of those married, 54.2% had children under age 18 living with them in the household and 46.7% had children under 6 (Figure 3G). Because the average age of first NIH award has crept upwards Rockey [2012b], these scientists are at crucial points in their careers. Any slowing down in advancement, pay, and productivity in this decade can have lasting effects on their entire careers Rogier and Padgett [2004].

Women between ages 40 and 60 can also face constraints and challenges in balancing work and family life. For PhD female scientists aged 40 to 49 from 2012-2014, 68.7% were married (Figure 3D). Of those married, 76.9% had children under age 18 in their households and 23.7% had children under 6. For women between the ages of 50 and 59 in 2012-2014, 70.3% were married and 26.6% of those women had children under age 18 in the household (Figure 3G). Female scientists at this age are also at a critical point in their careers, and advancing and leaning in to science and leadership positions could be a challenge to balance with family constraints. Having children ages 14-17 is a particular disincentive from moving for scientists Azoulay et al. [2016], and mobility is often seen as beneficial to scientific career progression Rodrigues et al. [2016]. Serious scrutiny needs to be given to the relationship of female scientists to the scientific workplace, as recent work has demonstrated that gender-neutral policies such as the tenure clock stopping policy have actually reduced female tenure rates while increasing male tenure rates Antecol et al. [2016]. If we can begin to get a better handle on understanding the types of work female scientists engage in and how they make career decisions at crucial points in their career, we can begin to understand the complex relationship women have with scientific careers.

Where Do We Stand Today?

Research has shown that graduate students in biomedical research appear rational in making decisions to enter graduate school, but that they do so based on the current year market information and have little information about the expected market in the year of their anticipated graduation Blume-Kohout and Clack [2013]. Additionally, junior scientists may not be aware of the current lack of future tenure-track academic positions available to trainees McDowell and Polka [2015], Polka [2014b]. They expect an academic career, and then later must be open to other PhD career paths when academic positions are not readily available. Transparency in career outcomes is lacking in biomedicine Polka et al. [2015]. Recent analysis of the labor market for the biomedical research workforce shows that supply is outstripping demand, with a labor gap across all degree levels (and using a conservative underestimate of the supply of biomedical scientists at both the graduate and postdoctoral levels), and identifies a need for training across a wide variety of skill sets Mason et al. [2016].

Junior researchers themselves have called for increased access to training opportunities, both in having the time to pursue career development activities (both academic and non-academic) and having access to sufficient resources to be able to make informed decisions and act as rational agents Dolan et al. [2016], Goodwin et al. [2015], McDowell et al. [2014]. As young scientists linger in postdoctoral positions, some of them will leave for non-academic positions, and a natural contraction in the academic workforce will take place. The stakes are high for this group since pursuing a career in scientific research requires heavy investments upfront.

We do not have an accurate picture of where PhDs go and which career routes put training to the best use Polka et al. [2015]. We have some idea that many more junior scientists wish to remain in academia than ultimately do Sauermann and Roach [2012, 2016], but also that these attitudes change upon reflection of values, exposure to career development opportunities, and awareness of career options Fuhrmann et al. [2011], Gibbs and Griffin [2013], Gibbs et al. [2014, 2015]. During graduate school, the number of PhDs who want to remain in academia decreases but is still greater than 50% at completion of graduate studies Sauermann and Roach [2012].

Not all established scientists and mentors share the same values for how science contributes to society Gibbs et al. [2014] and how career development opportunities can influence preferences in career advancement Gibbs et al. [2015]. There is little value placed by our current academic culture on education, literacy, communication, and non-tenure positions, meaning that these are considered a “plan B” or “alternative” for scientists. It follows that there is a lack of thoughtful planning for those careers, which

means junior scientists spend too much time acquiring technical skills they do not use in subsequent non-academic careers. Society may benefit in the short term from research, but in the long term may suffer from such investment in training almost exclusively for bench science. Career development itself can be developed as a scholarly academic pursuit to train a sustainable workforce as well as a larger research enterprise Fuhrmann et al. [2011], Fuhrmann [2016]. As a scientific enterprise, we should consider the ways in which we value, track and promote our next generation of scientists to benefit both academia and society at large.

The Doubling Boomers have entered the labor market and will continue to enter as they finish academic and postdoctoral training. Nationally representative household survey data shows that almost half (45.6%) of the growth in the PhD biomedical workforce between 2007 and 2011 is individuals under age 45. Meanwhile, the abolition of retirement at age 65 in academia has increased the number of scientists in the workforce aged 65 and older. The abolition of mandatory retirement at universities slowed down the rate of openings for entry-level faculty positions for younger independent scientists. Although the aging of the academic workforce (as measured by the PI Replacement Index Heggeness et al. [2016a]) suggests that there may be opportunities for Doubling Boomers in the near future, young scientists today have fewer options for a successful career path in academic medicine than many of their predecessors, which may in turn be placing pressure on how junior scientists practice science Maher and Sureda Anfres [2016], Oni et al. [2016], Powell [2016], Editorial [2016].

An important implication is the imbalance between growth in the number of young scientists and academic principal investigator positions. If opportunities in academic medicine do not exist or are not appealing, these Doubling Boomers will (and are) go(ing) into the private sector, government, or potentially leave the biomedical workforce entirely. This means that the ultimate outcome of training is different for most Doubling Boomers than it was for their mentors. As previously mentioned, that raises the question heard today in many circles of whether there are too many trainees, if training should be different, or if academia should create more non-training positions for them (e.g. staff scientists).

There are also real questions for the diversity of the biomedical workforce and the larger scientific enterprise. A recent summary of reports providing recommendations on improving the biomedical enterprise found that out of 267 recommendations across 9 reports, 0.7% addressed issues of diversity and inclusion Pickett et al. [2015]. We agree with Pickett et al. that "Diversity must be a part of any reform discussion because workforce changes. . . will inevitably affect diversification efforts...The scientific community must. . . identify and reform structural inequities. . . that select against women and underrepresented minorities" Pickett et al. [2015]. Anecdotal reasons cited for not considering these issues include

"others are working on this, so I don't need to" and "diversity is a K-12 [i.e. pre-college] problem", and even "diversity issues are too complex to solve" Pickett [2016], despite the attraction scientific research holds for many wishing to solve difficult problems. A focus on diversifying the independent research workforce in academia and elsewhere must be on the forefront of any policy developments.

Conclusion

The scientific enterprise has evolved in such a way that the labor market today looks nothing like its past. Our young scientists are grappling with issues of huge significance regarding their future in science. Innovation and novelty is occurring today in the private sector more than it ever has, and many of our young scientists are choosing careers in Pharma, private industry, and government over academe. Additionally, young scientists are moving to labs abroad more frequently than in the past. To plan appropriately for these shifting market trends, we need to know and understand the data. More importantly, we need to use the data to help inform decision-makers and drive policy.

We have provided a historical overview of trends in the development and advent of the PhD biomedical workforce and presented global trends from the turn of the 20th century around the establishment of the NIH. We have also discussed important demographic shifts in the workforce over the past five decades. Our hope is that this information gives background, context, facts and data to the continuing discussion about the health and wellbeing of the U.S. biomedical workforce and that it helps inform policy makers and young scientists considering a career path in biomedical science. In the end, having a workforce that thrives, creates opportunity, and is inherently innovative is what we all aspire to. By making decisions informed with the latest and best data and estimates, we hope to help achieve these goals.

Appendix 1: Known Unknowns: The Postdoc Problem

Postdoctoral scholars are perhaps the Doubling Boomers about whom the least data are currently available. Estimates of the number of postdocs in the United States vary widely, from less than 30,000 to nearly 80,000 Biomedical Research Workforce Working Group [2012], Ferguson et al. [2014], National Science Foundation [d]. Current sources of data about postdocs either rely on institutions accurately knowing how many postdocs they employ or only include individuals who have received a PhD in the United States, omitting the foreign-trained (Appendix Table 1). It has been estimated that more than 60% of the postdocs in the United States are on temporary visas Ferguson et al. [2014]. While non-citizens make up a large portion of the postdoc workforce, it is not known how many received their PhDs outside the U.S., because these data are not collected.

Institutions often do not know with any accuracy how many postdocs they employ Biomedical Research Workforce Working Group [2012]. Because postdocs serve in a dual role as both trainees and employees National Institutes of Health [2014], U.S. Government [2014], they are often not eligible for the same benefits as other employees; this fact, combined with the multiple funding mechanisms by which they may be paid (such as fellowships and research grants) means that they often do not fit neatly into institutional HR or payroll systems. This may account for the plethora of job titles used for postdocs: at many institutions, postdocs may have different job titles depending on their source of funding, and some institutions have more than 20 different job titles for postdocs Ferguson et al. [2014], McDowell [2016b]. Some postdocs, particularly those on foreign fellowships or fellowships from private foundations, may not appear in institutional human resources or payroll databases at all, as they are not paid through the institutions at which they work. Additionally, many biomedical postdocs are employed at university-affiliated hospitals; however, these are often administratively separate entities from their affiliated universities, and the Postdoctoral Office (if it exists) may not have access to information about, and thus may not be aware of, postdocs employed at affiliate medical centers. This has most recently led to administrative difficulties in raising postdoctoral salaries (or moving postdocs to hourly, overtime-eligible positions) in response to updates to the Fair Labor Standards Act (FLSA, Bankston and McDowell [2016]).

Source	Method	Target Population	Limitations	Reported Postdoc Number
SED[2] (Survey of Earned Doctorates)	Annual census	Individuals receiving Ph.D. from U.S. academic institution	Omits foreign-trained doctorates and the ∼50% of survey participants without definite postgraduation commitments at time of survey; only covers incoming population for given year	**9,635** *(2013)*[3]; **9,418** *(2014)*[4] **9,812** *(2015)*[5]
SDR[6] (Survey of Doctorate Recipients)	Longitudinal biennial survey (sample, not census)	Individuals with Ph.D. in SEH fields from U.S. academic institution	Omits foreign-trained doctorates, those in non-SEH (Science, Engineering, Health) fields	**27,100** *(2013)*[7]
GSS[8] (Graduate Student Survey	Annual census	U.S. institutions[9], federal labs[10] SEH grad degree-conferring depts	Based on institutional data; omits non-SEH fields, academic departments that lack graduate programs, industry & government	**61,942** *(2013)*[11]
HERD[12] (Higher Ed Research & Development Survey)	Annual survey of institutions	U.S. institutions that spend at least $150,000 per year on R & D	Based on institutional data[13]; limited to R & D personnel; omits industry & government	**66,363** *(2013)*[14]
NPA Institutional Policy Report	Survey of postdoc officers	167 sustaining[15] member institutions of NPA	Based on institutional data (often estimates)	**79,000** *(2013)*
ECD[16] (Early Career Doctorates Project)	Survey (sample, not census)	Doctorate recipients within past 10 years (both U.S. and foreign-trained)	Still in pilot stage	N/A

Appendix Table 1: Major sources of data about the U.S. postdoc workforce
See Notes on next page.

Notes:

[2] http://www.nsf.gov/statistics/srvydoctorates/

[3] Table 51. Definite postgraduation commitments of doctorate recipients, by citizenship status and major field of study: 2013 http://www.nsf.gov/statistics/sed/2013/data/tab51.pdf

[4] Table 51. Definite postgraduation commitments of doctorate recipients, by citizenship status and major field of study: 2014 http://www.nsf.gov/statistics/2016/nsf16300/data/tab51.pdf

[5] Table 51. Definite postgraduation commitments of doctorate recipients, by citizenship status and major field of study: 2015 https://www.nsf.gov/statistics/2017/nsf17306/data/tab51.pdf

[6] http://www.nsf.gov/statistics/srvydoctoratework

[7] Table 75. Doctoral scientists and engineers employed as postdoctoral appointees, by field of doctorate: 2013 http://ncsesdata.nsf.gov/doctoratework/2013/html/SDR2013_DST75.html

[8] http://www.nsf.gov/statistics/srvygradpostdoc/

[9] "All academic institutions in the United States and its territories (Guam and Puerto Rico) that grant research-based master's degrees or doctorates in SEH fields as of fall 2013. This includes data for branch campuses, affiliated research centers and health facilities, and separately organized components, such as medical or dental schools, schools of nursing, and schools of public health."

[10] Survey of Postdocs at Federally Funded Research and Development Centers http://www.nsf.gov/statistics/srvyffrdcpd

[11] Table 32. Postdoctoral appointees in science, engineering, and health in all institutions, by detailed field: 2007-13 http://ncsesdata.nsf.gov/gradpostdoc/2013/html/GSS2013_DST_32.html

[12] http://www.nsf.gov/statistics/srvyherd/

[13] "Potential sources of measurement errors include incomplete administrative data or differing categories used by the institutions."

[14] Table 74. Headcount of R & D personnel at higher education institutions, by state, institutional control, and institution: FY 2013 http://ncsesdata.nsf.gov/herd/2013/html/HERD2013_DST_74.html

[15] Mostly academic institutions; also some national labs

[16] http://www.nsf.gov/statistics/srvyecd/

In the early 2000s, few institutions had postdoctoral offices responsible for oversight of postdoctoral scholars; as of 2014, there were over 150 postdoctoral offices in the U.S. Ferguson et al. [2014]. While these offices exist to, among other things, collect data about postdoctoral scholars, many such offices still may not know how many postdoctoral scholars they serve.

The National Science Foundation (NSF) is responsible for collecting data about the biomedical workforce in the U.S. Congress of the United States of America [2012]. Two NSF surveys, the Survey of Earned Doctorates (SED, National Science Foundation [a]) and the Survey of Doctorate Recipients (SDR, National Science Foundation [b]), though often cited as sources of data about the number of postdocs in the U.S., do not (and were not designed to) provide this information.

Both the SED and the SDR include only individuals who have received a PhD in the United States. The SED is completed by more than 90% of individuals around the time that they complete their PhDs, and includes questions about the respondents' next job, for those holding offers. It therefore provides a minimum number of new PhDs entering the postdoc pool each year, but does not capture doctorate recipients from previous years who remain in the postdoc pool, or provide data about how long PhDs remain in their postdoc positions.

Because about half of respondents do not have a firm employment commitment when they complete the survey, they are not included in the number of new postdocs provided by the SED. Of the 12,504 people who received a PhD in the life sciences in the U.S. in 2014, less than half (48.8%) had definite commitments at the time they completed the survey. Thus, the available data showed that about a third (29.4%) had a commitment to do a postdoc; less than a tenth (7.1%) were taking a non-postdoc academic position in the U.S.; less than five percent had jobs in industry (4.7%), "other" in the U.S. (3.4%), or abroad (4.1%), while more than half (51.2%) had no definite plans for employment (see Table 51 (https://www.nsf.gov/statistics/2016/nsf16300/data/tab51.pdf). Likewise in 2015, of the 12,520 who received a PhD in the life sciences in the U.S., 49.2% had definite commitments at the time they completed the survey: 28.8% had a commitment to do a postdoc; 7.3% were taking a non-postdoc academic position in the U.S.; 5.3% had jobs in industry; 3.4% were marked "other" in the U.S., and 4.2% abroad. Again, more than half (50.9%) had no definite plans for employment (Figure 2E, see Table 51 (https://www.nsf.gov/statistics/2017/nsf17306/data/tab51.pdf)).

The Survey of Doctorate Recipients is a longitudinal, career-long study of a subset of individuals who receive a science or engineering PhD in the U.S. in a given year (i.e. a sample of SED respondents). Because it follows individuals throughout their careers, it collects data about the later employment of

those who did not have firm commitments upon completing the SED, but only includes individuals who received a PhD in a science or engineering field from a U.S. institution, not those who received their doctorates abroad or in another field. Because of these reasons, the number of postdocs identified by the SDR is not necessarily an accurate measure of the number of postdocs in the U.S.

More comprehensive estimates of the number of postdocs in the U.S. are provided by three surveys of academic institutions. The NSF's Survey of Graduate Students and Postdoctorates in Science and Engineering (GSS, National Science Foundation [c]) and Higher Education Research and Development Survey (HERD, National Science Foundation [d]) are annual censuses of certain U.S. academic institutions; both surveys ask institutions to provide information about their graduate students and postdocs. The Institutional Policy Survey of the National Postdoctoral Association (NPA, National Postdoctoral Association) collects a broader range of data, including average salary and available benefits, about postdocs at the NPA's 167 sustaining member institutions, and thus provides a more comprehensive view of postdoc employment conditions at U.S. academic institutions. Because they are not dependent upon SED data, these surveys capture individuals with foreign doctorates. However, the data they provide is only as good as the data institutions collect about their postdocs. Additionally, they are limited to certain types of academic institutions (and thus may miss postdocs employed in industry, non-profits, government and other organizations). Although these three surveys are methodologically similar, they provide disparate estimates of the number of postdocs working at U.S. academic research institutions. In 2013, the GSS captured data about 62,000 postdocs; HERD identified more than 66,000; and the NPA's Institutional Policy Survey, 79,000.

Taking all available sources into account, it is clear that the data available are both limited and flawed. Of particular interest is the considerably higher estimate of postdoc numbers found by the NPA compared to the NSF. The sheer range of estimates in the number of postdoctoral researchers represents a systemic institutional failure to identify and track postdocs at institutions, leading to frustrations in collecting accurate data on a population that represents an essential part of the academic career ladder. This inability to collect data inhibits the scientific enterprise from gauging the role and value of postdoctoral researchers, and therefore from making informed policy decisions Pierre [2016].

The reasons for taking a postdoc in the first place appear to be a lack of awareness of non-academic jobs and defaulting into the academic track, a lack of career preparation for academic and non-academic jobs, and over-confidence in the ability to obtain a faculty position Sauermann and Roach [2016]. The postdoc and PhD populations are thus intricately linked: the number of postdocs increases with increasing graduating PhD class size, and is inversely proportional to the number of faculty positions Stephan

[2012]. It follows that discussions of unemployment for PhDs, and policy recommendations thereof, must be tightly coupled to discussions of (un)employment and under-employment after completion of postdoctoral training, otherwise they are a distraction from the problems at hand, and again the lack of available data on non-academic employment post-PhD frustrates these efforts McDowell [2016a].

The only postdocs that we are currently able to track well are those who remain within academia, either in the postdoc pool, or as faculty. But there are a wealth of questions which we simply cannot answer while postdoc identification and data collection efforts are sparse. How many postdocs leave the U.S. after training and go elsewhere? How many enrich the U.S. workforce? How many stay and become citizens/resident aliens? What is the value of postdoctoral training to the individual, to the scientific enterprise, and to society?

The lack of visibility about the postdoc position was identified as a problem in 1969 Curtis [1969]. Efforts are still under way in 2016 to get institutions to identify and track all of their postdocs Callier [2016], McDowell [2016b] and the inability to do so led to widespread confusion, and a lack of effective communication by institutions with their postdocs and faculty, about changes for postdocs caused by updates to the Fair Labor Standards Act (FLSA, Bankston and McDowell [2016]), and then by the injunction granted against them shortly before their date of implementation. The only certainty about postdoc data is that the data are uncertain, and despite nearly 50 years of discussion, data (and the reforms and modernization of the postdoctoral position that depend upon its collection) are not forthcoming Biomedical Research Workforce Working Group [2012], National Academies [2014], Curtis [1969], National Academies [2005, 1998, 1994, 2011a], Physician-Scientist Workforce Working Group [2014], National Academies [2000]. This creates severe challenges in tracking, or even counting, this diverse population, and speaks to the value placed on postdoctoral researchers by the research enterprise thus far. Also, despite being called a "trainee" position, there are no formal criteria for successful completion of training, nor is this measured, and the definition of "success" in postdoctoral training may be limited to paper publication or securing a tenure-track position. This is worrisome, given the strong dependence the academic system has on postdoctoral researchers Stephan [2013] and the barrier to the stated mission of increasing faculty diversity this creates Gibbs et al. [2016]. It is imperative that postdocs be identified and tracked to enable accurate discussions about their role and value in science.

Appendix 2. Data and Methods

For the purposes of this paper, we use U.S. decennial census and American Community Survey (ACS) microdata from the Minnesota Population Center's Integrated Public-Use Microdata Series (IPUMS) — USA project. We create a unique extract of all biomedical scientists and their household members using the decennial 1% samples from 1850 through 2000. Note that for 1970 we use the 1% metro form 2 data and 1980 is the 1% metro data. The 2010-2014 ACS data are 1% samples. We also use the 2012-2014 ACS 3-year file for some statistics, which represents approximately 3% of the U.S. population. These data are publicly available for any researcher(s) to extract through usa.ipums.org.

Our sample keeps only those households who have at least one "biomedical scientist" living in the household. For the purpose of our study, we define a "biomedical scientist" using the IPUMS occupation variable for 1950 (OCC1950), which in an effort to harmonize the occupation variable overtime "applies the 1950 Census Bureau occupational classification system to occupational data" in other years. For more information regarding the harmonization of occupation in the IPUMS datasets we use, see: https://usa.ipums.org/usa-action/variables/OCC1950#comparability_section. We identify three particular occupation codes for our definition of "biomedical scientists": 13 — Professors and instructors in the biological sciences, 19 — professors and instructors in the biological sciences, 62 — biological scientists.

We use three definitions of biomedical scientists. The first (Definition 1) is the one outlined above based only on the occupation codes 13, 19 and 62. The second (Definition 2) limits Definition 1 to only those with 5 or more years of education. The third (Definition 3) the most restrictive. It keeps only those in Definiton 2 with Doctoral Degrees. Definition 1 is available from 1850 to 2010. Definition 2 is available from 1960 to 2010, and Definition 3 is available from 1990 to 2010. Because of the differences in timeframe and availability of data, we move back and forth among definitions in the paper. When we want to reach back historically, we lose precision in our ability to precisely define those with advanced degrees or, in some instances, those with more than 5 years of university training. In recent years, we opt to use Definition 3 since that is the most relevant for our population of study. The definition used is carefully documented each time it is discussed.

Given that biomedical researchers include not only those with a PhD, but also those with an MD or equivalent professional degree, we additionally create a fourth definition that is defined as occupational codes 13, 19, and 62 and educational attainment as PhD or advanced professional degree. We present those statistics in supplemental documents (Supplemental Table 1, Supplemental Table 2) for individuals who are interested in a biomedical workforce that includes MDs and equivalent professional degrees.

We define race using the main IPUMS variable for race. Because our sample is small and historical, we are limited in our ability to expand on race and ethnic categories for this study. We define "white" as any individual who is identified as white only in the data. We define "black" as anyone who is identified as black only in the data. Finally, we define "other" as anyone who is identified as any other race in the data. For more information on how racial categories are harmonized overtime, see: https://usa.ipums.org/usa-action/variables/RACE#comparability_section.

Industry is defined using the IPUMS variable for industry that harmonizes the industry codes to the 1990 industrial definitions (IND1990). We define "academic" as all colleges and universities. "Public" is defined as anyone in public administration, which includes individuals in federal, state, and local governments. "Private" are all other industrial codes, excluding military and non-response.

Other variables are defined as follows. Citizenship is defined as a U.S. citizen born in the U.S. or born abroad of American parents, a naturalized citizen, or a non-citizen. Income is personal income adjusted for inflation (CPI-deflated — 2000 base). All counts use the person weight variable to obtain nationally representative counts (Stata command [pweight=perwt]).

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Jose Pacas, PhD Candidate, is an Economist in the Poverty Statistics Branch of the U.S. Census Bureau. The data analysis for this paper was developed when he was a PhD student at the University of Minnesota and working as a consultant for the National Institutes of Health.

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MLH, KTWG and JP carried out data analysis. All authors contributed to writing the paper. MLH

and GSM oversaw writing and design of paper. All comments and opinions are solely of the authors and do not necessarily represent the position of any federal agency.

Comments

Comments can be made by contacting the corresponding authors at misty.l.heggeness@census.gov and garymcdow@gmail.com

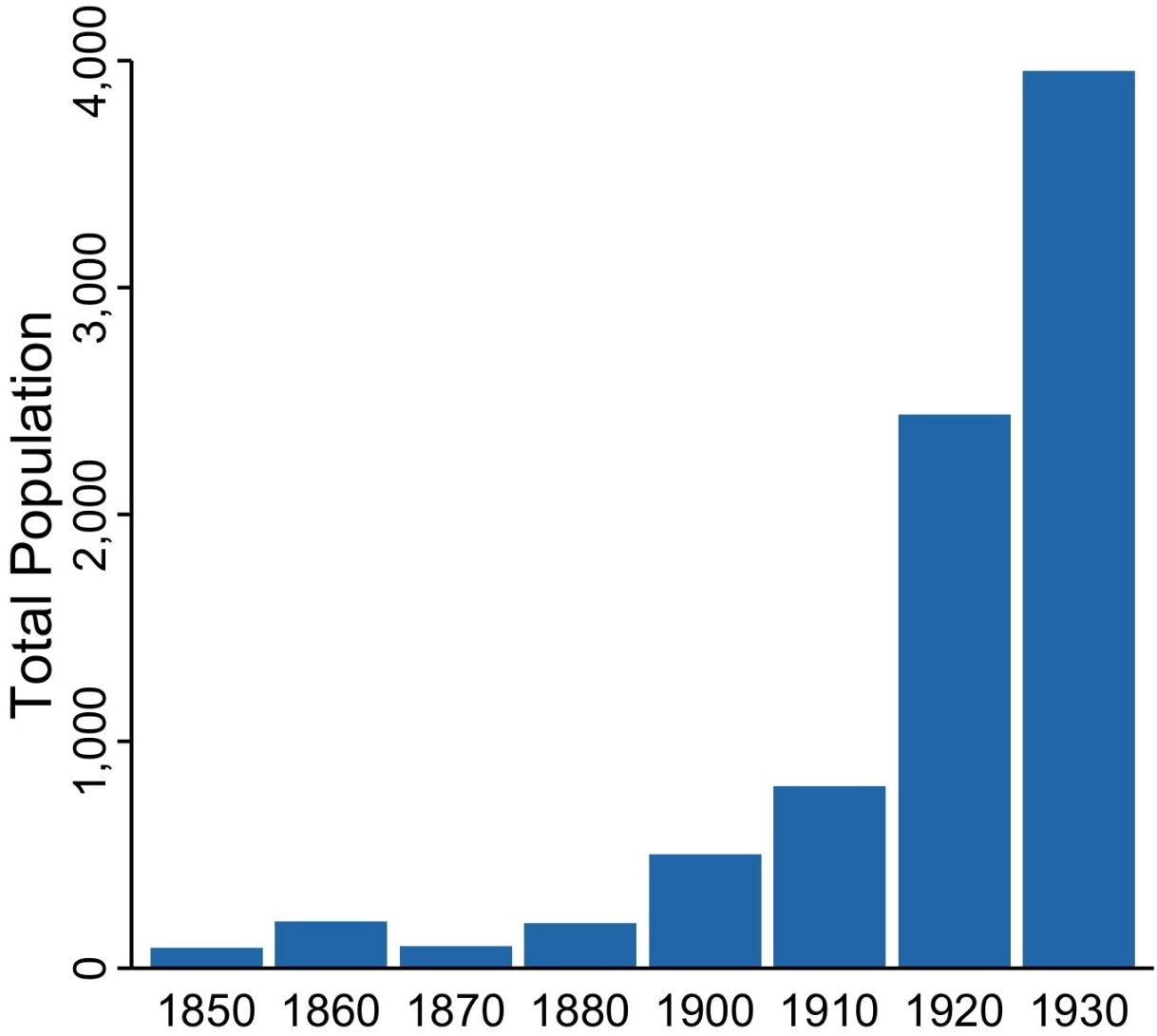
Supplementary Materials

Year	1990		2000		2010		2014	
	N	s.e.	N	s.e.	N	s.e.	N	s.e.
Total Population	37,299	(193)	72,423	(269)	96,425	(311)	87,185	(295)
Sex								
Male	26,083	(162)	45,444	(213)	53,459	(231)	49,409	(222)
Female	11,216	(106)	26,979	(164)	42,966	(207)	37,776	(194)
Citizenship Status								
Citizen	28,182	(168)	37,495	(194)	47,852	(219)	42,400	(206)
Naturalized	3,347	(58)	9,550	(98)	14,849	(122)	17,055	(131)
Non-Citizens	5,770	(76)	25,378	(159)	33,724	(184)	27,730	(167)
Race								
White, non-Hispanic	30,457	(175)	44,994	(212)	54,808	(234)	49,435	(222)
Black, non-Hispanic	561	(24)	1,841	(43)	4,052	(64)	2,605	(51)
Asian, non-Hispanic	5,350	(73)	21,653	(147)	30,716	(175)	29,247	(171)
Other, including Hispanic	931	(31)	3,935	(63)	6,849	(83)	5,898	(77)
Industry								
Private	17,357	(132)	46,848	(216)	68,225	(261)	63,305	(252)
Academic	17,725	(133)	19,988	(141)	20,271	(142)	16,709	(129)
Public	2,217	(47)	5,587	(75)	7,929	(89)	7,171	(85)
Education								
MA/Prof. Degree	9,874	(99)	15,780	(126)	19,488	(140)	17,895	(134)
PhD	27,425	(166)	56,643	(238)	76,937	(277)	69,290	(263)

Supplemental Table 1: Descriptive Statistics of Biological and Medical Scientists with a PhD, MD, or equivalent professional degree, United States, 1990 to 2014 Source: Author's calculations, IPUMS decennial censuses, IPUMS ACS 2010 and IPUMS ACS 2014 (https://www.ipums.org/).

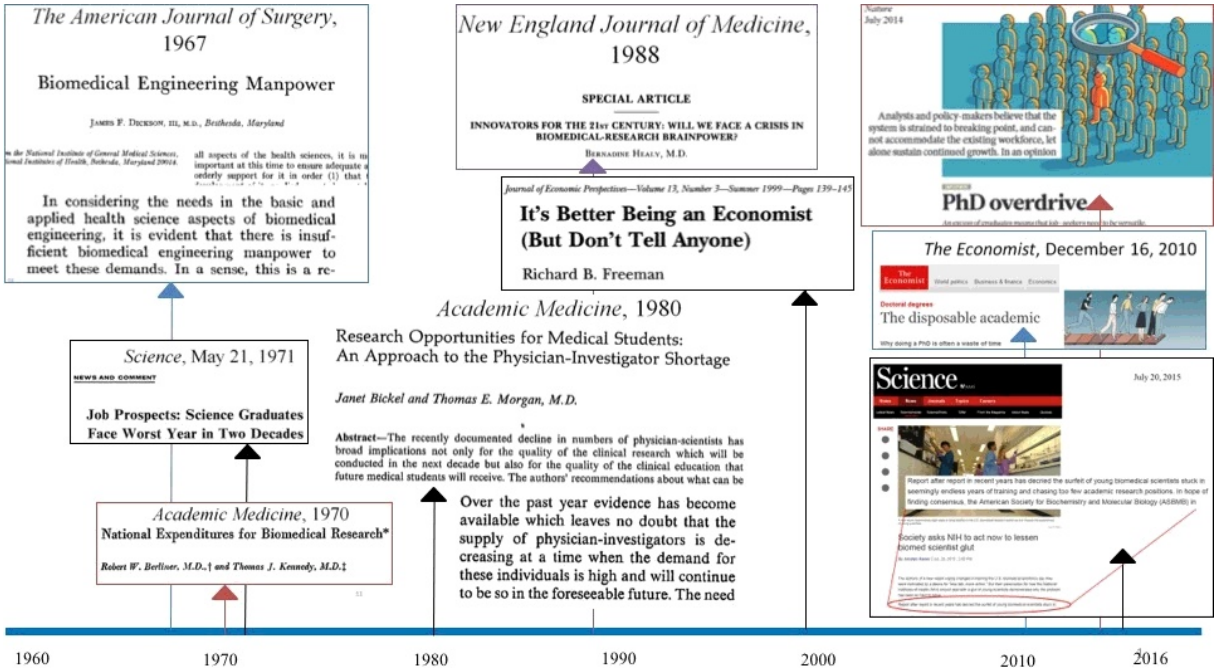
Age Group	<45		45-54		55-64		65+		Total Population	
	N	s.e.	N	s.e.	N	s.e.	N	s.e.	N	s.e.
Year										
2002	40,972	(202)	16,590	(129)	3,959	(63)	3,968	(63)	65,489	(256)
2003	45,304	(213)	16,758	(129)	10,580	(103)	4,836	(70)	77,478	(278)
2004	45,955	(214)	21,540	(147)	6,860	(83)	2,923	(54)	77,318	(278)
2005	51,232	(226)	18,484	(136)	9,656	(98)	3,485	(59)	82,857	(288)
2006	48,961	(221)	20,723	(144)	10,112	(66)	4,371	(66)	84,167	(290)
2007	45,960	(214)	14,460	(120)	10,265	(101)	3,103	(56)	73,778	(272)
2008	48,597	(220)	17,518	(132)	11,822	(109)	3,924	(63)	81,861	(286)
2009	50,464	(225)	20,667	(144)	12,871	(113)	5,776	(76)	89,778	(300)
2010	56,366	(237)	21,502	(147)	12,581	(112)	5,976	(77)	96,425	(311)
2011	55,154	(235)	22,111	(149)	13,757	(117)	4,841	(70)	95,863	(310)
2012	54,998	(235)	22,137	(149)	13,576	(117)	7,077	(84)	97,788	(313)
2013	49,362	(222)	19,300	(139)	15,351	(124)	7,831	(88)	91,844	(303)
2014	50,519	(225)	20,065	(142)	10,466	(102)	6,135	(78)	87,185	(295)

Supplemental Table 2: Age Distribution of Biological and Medical Scientists with PhD, MD, or equivalent professional degrees, United States, 2002 to 2014 Source: Authors' calculations, IPUMS ACS 1% files (https://www.ipums.org/).



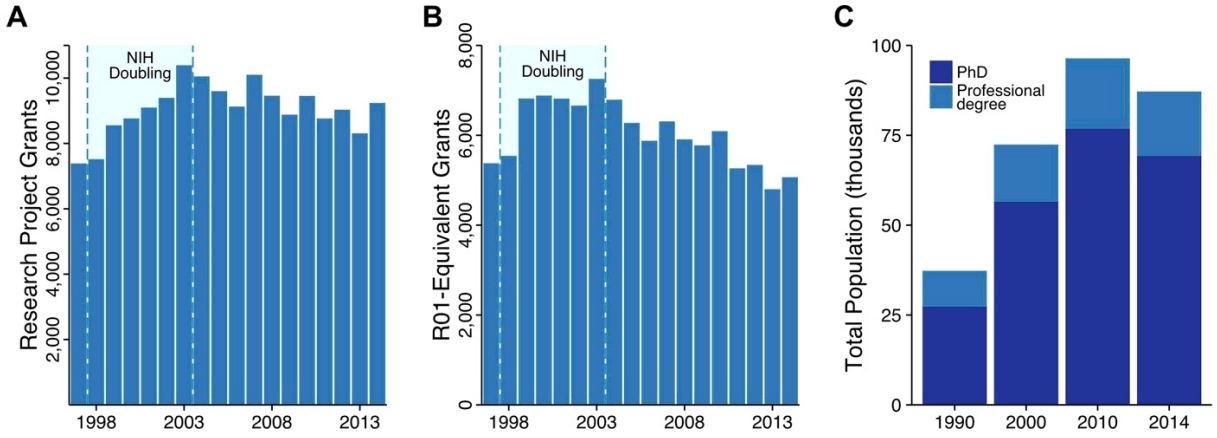
Supplementary Figure 1: All biological and medical scientists in the U.S., 1850-1930.

Source: Authors' calculations, IPUMS-USA decennial census data (https://www.ipums.org/)



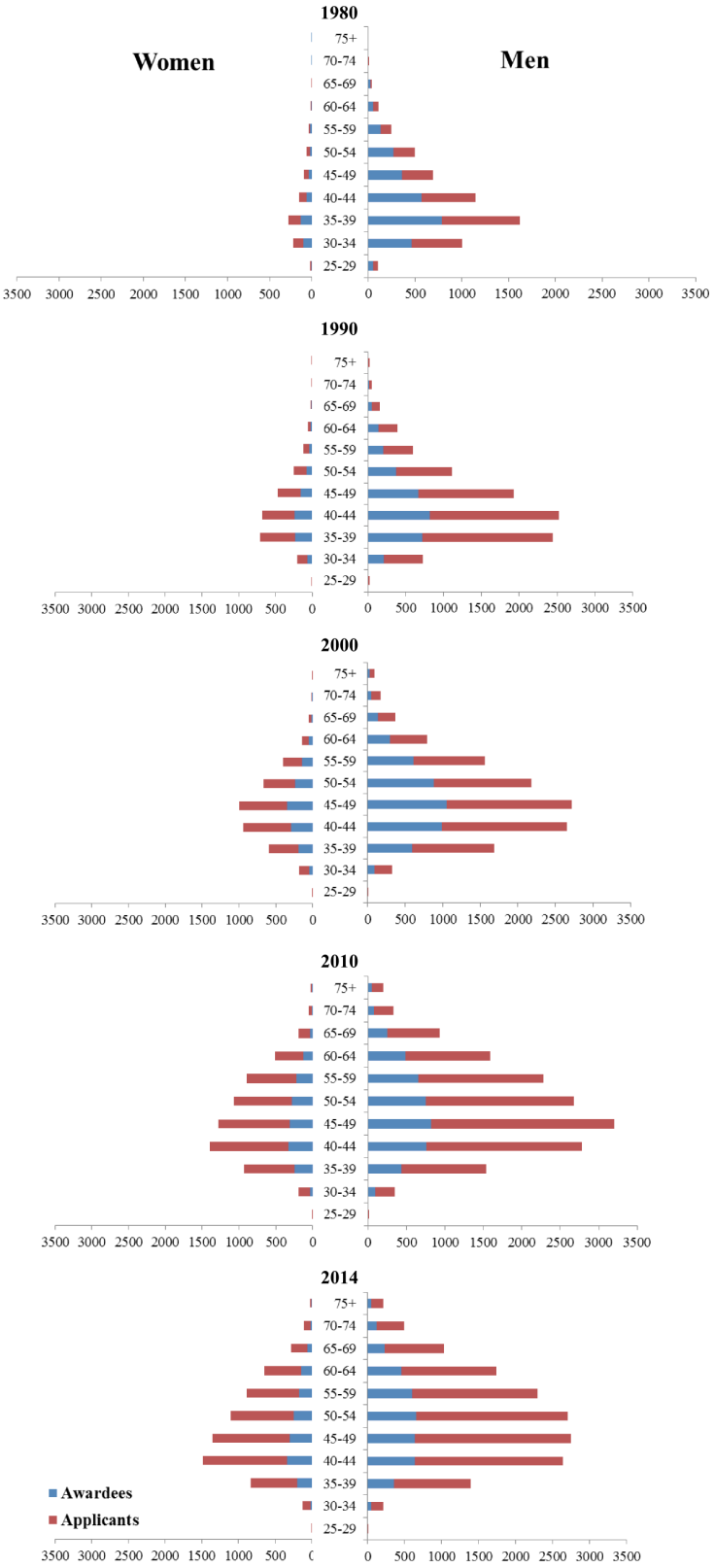
Supplementary Figure 2: Timeline of Literature on Over and Under Supply of Biomedical Scientists, 1960-2016.

Articles in the 1970s and 1990s-present day argue a period of oversupply of biomedical research scientists in the scientific workforce. Articles in the 1960s and 1980s discuss a period of undersupply of biomedical research scientists in the scientific workforce.



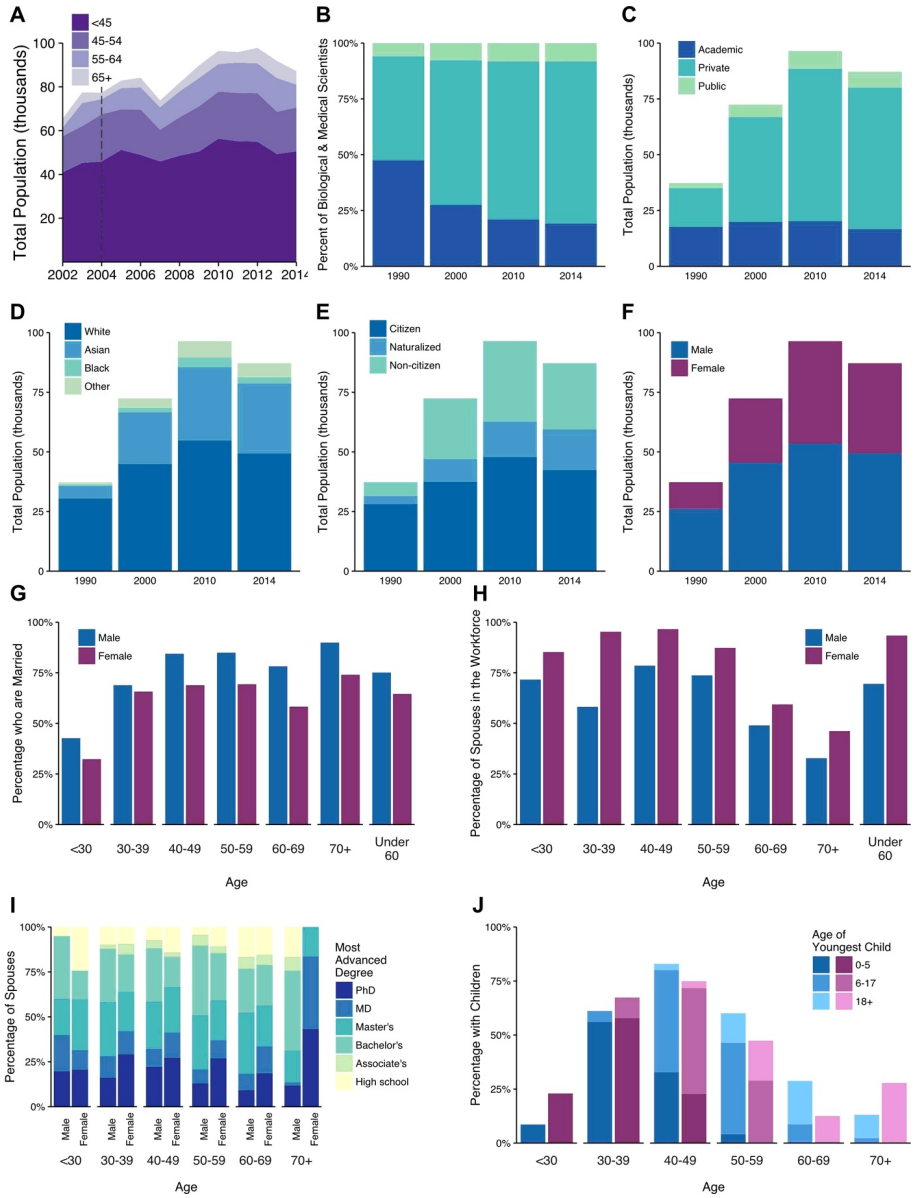
Supplementary Figure 3: The NIH Doubling.

A. Research Project Grants, 1997-2014. B. R01-equivalent grants, 1997-2014. C. Biological and medical scientists with a PhD, MD, or equivalent professional degree, 1990-2014.



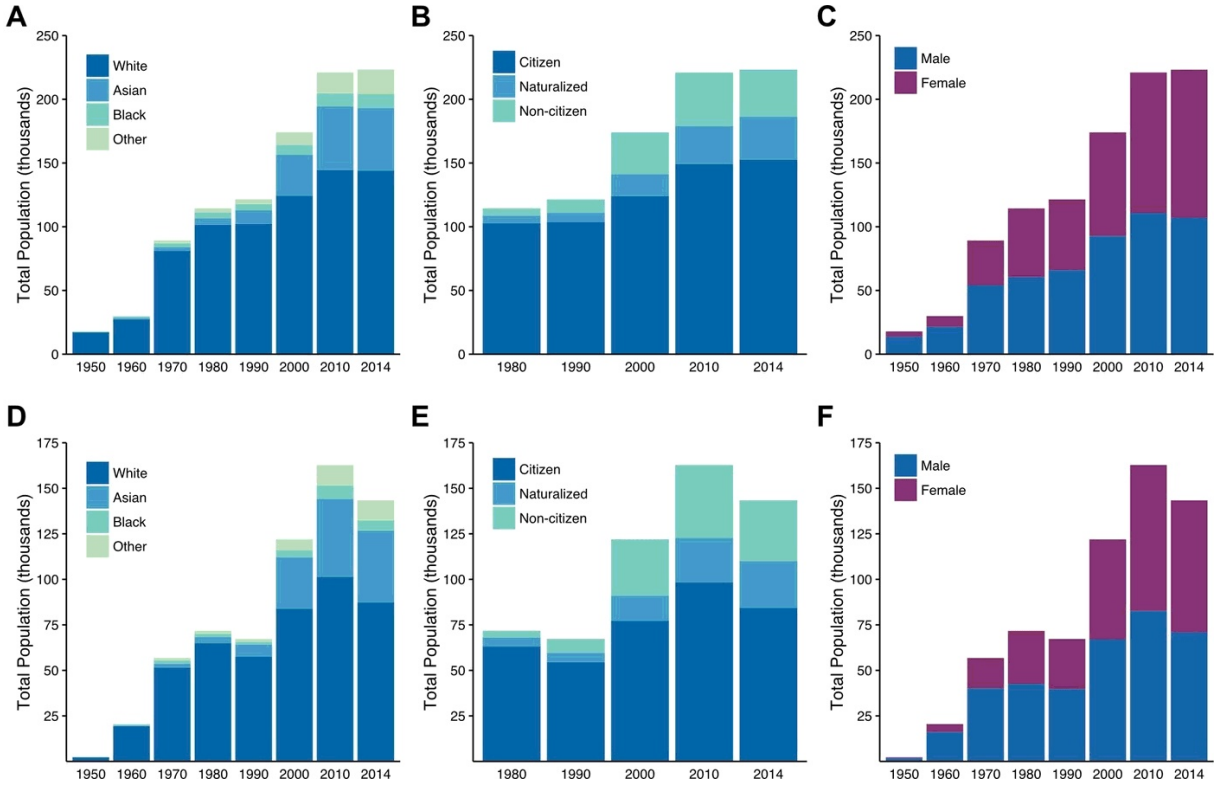
Supplementary Figure 4: Age Pyramids by Age and Gender, 1980 to 2014.

Independent Investigators (R01-Equivalent) Applicants and Awardees by Age Group and Gender, 1980-2014. Notes: Authors' calculations using the National Institutes of Health Information and Management, Planning, and Coordination II (IMPACII) Administrative Data, accessed on March 10, 2015.

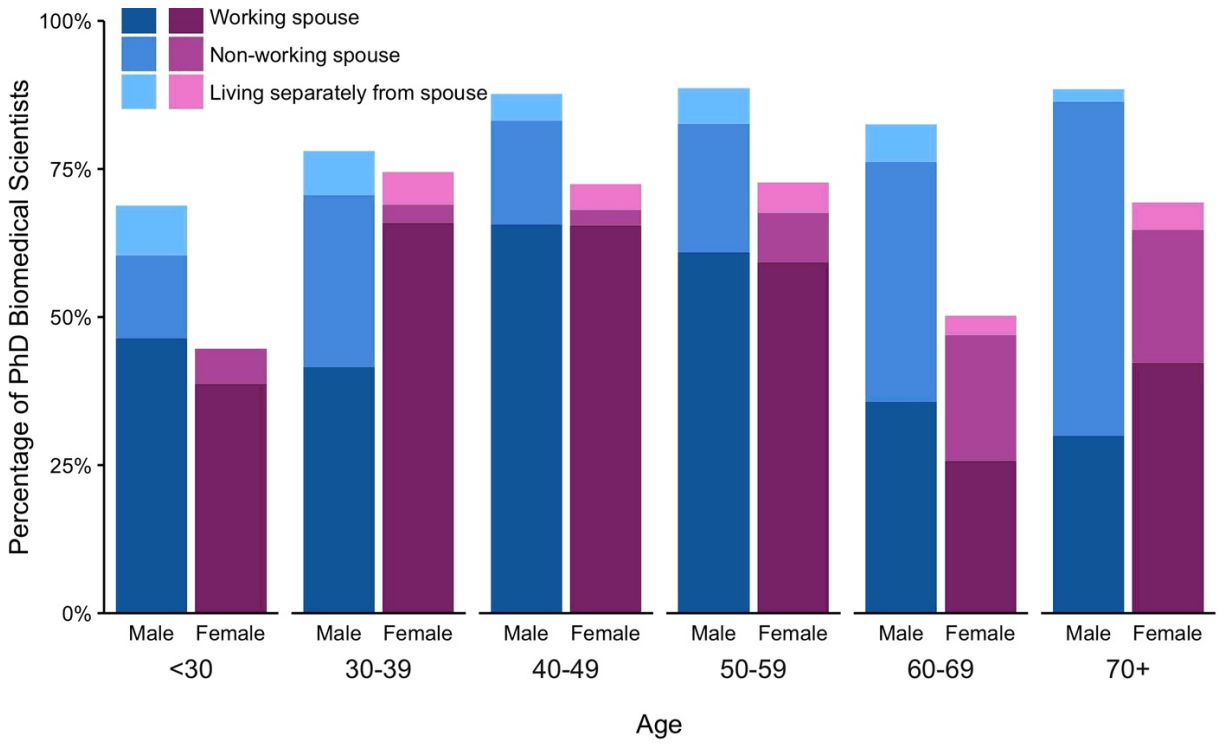


Supplementary Figure 5: The changing face of the American biomedical PhD, MD, and equivalent professional degree workforce, 1990-2014.

A. Biomedical workforce by age group. B. Proportion of biomedical workers by industry. C. Number of biomedical workers by industry. D. The biomedical workforce has become more racially diverse over time. E. Non-citizens make up an increasingly large proportion of the U.S. biomedical workforce. F. The proportion of women in the biomedical science workforce has increased over time. G. Percentage of biomedical scientists who are married, by scientists' age and gender, pooled 2012-2014. H. Labor force status of biomedical scientists' spouses, by scientists' age and gender, pooled 2012-2014 shows that female biomedical scientists have a higher rate of working spouse. I. Educational attainment of biomedical scientists' spouses, by scientists' age and gender (pooled 2012-2014) shows that women have higher rates of a spouse with a PhD or professional degree than men. J. Percent of married biomedical scientists with children, by scientists' age and gender, pooled 2012-2014.



Supplementary Figure 6: Demographics of the U.S. biomedical workforce, all levels of education (A-C) and those with 5+ years of university education (D-F). A. & D. The biomedical workforce has become more racially diverse over time. B. & E. Non-citizens make up an increasingly large proportion of the U.S. biomedical workforce. C. & F. The proportion of women in the biomedical science workforce has increased over time.



Supplementary Figure 7: Female biomedical scientists are more likely to have a spouse who is also in the labor force.

(2010 IPUMS data) Scientists with a PhD; 2012-2014 ACS 3-year file.

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