Volume Title: U.S. Engineering in a Global Economy

Volume Author/Editor: Richard B. Freeman and Hal Salzman, editors

Volume Publisher: University of Chicago Press

Volume ISBNs: 978-0-226-46833-4 (cloth); 978-0-226-46847-1 (e-ISBN)

Volume URL: http://www.nber.org/books/free12-1

Conference Date: September 26–27, 2011

Publication Date: April 2018

Chapter Title: Dynamics of Engineering Labor Markets: Petroleum Engineering Demand and Responsive Supply

Chapter Author(s): Leonard Lynn, Hal Salzman, Daniel Kuehn

Chapter URL: http://www.nber.org/chapters/c12693

Chapter pages in book: (p. 243 – 262)

8

Dynamics of Engineering Labor Markets
Petroleum Engineering Demand and Responsive Supply

Leonard Lynn, Hal Salzman, and Daniel Kuehn

8.1 Introduction

The dynamics of engineering labor markets are controversial. Some believe they are similar to other labor markets, in which the supply of workers is responsive to demand as reflected in salaries. As the demand for engineers increases, salaries increase, motivating more students to major in engineering and more incumbents to stay in engineering. Others assert that the specialized knowledge and arduous education and training required of engineers inherently limit the size of the labor pool. According to this view, the U.S. education system does not produce a sufficient number of qualified engineers to meet national needs. One problem is said to be a lack of interest in the profession of engineering by American young people, especially women and some minorities. Another is a supposed weakness in the U.S. K–12 education system which, it is claimed, does not produce a sufficient number of high school graduates qualified to enter university engineering programs.

Leonard Lynn is Professor Emeritus at Case Western Reserve University. Hal Salzman is Professor of Planning and Public Policy at the Edward J. Bloustein School of Planning & Public Policy and Senior Faculty Fellow at the John J. Heldrich Center for Workforce Development at Rutgers University. Daniel Kuehn is research associate at The Urban Institute.

The research was supported through grants from the Alfred P. Sloan Foundation and the National Science Foundation (Human and Social Dynamics Program, no. SES-0527584; Social Dimensions of Engineering, Science, and Technology no. 0431755). Research assistance was provided by Purba Ruda. Parts of this chapter are drawn from Lynn and Salzman (2010) and Salzman and Lynn (2010). Professor Thomas K. Holley, Director of the Petroleum Engineering Program at the University of Houston, was also kind enough to read a draft of this chapter and make suggestions and comments. The authors, of course, take full responsibility for the chapter's conclusions and any factual errors that might remain in it. For acknowledgments, sources of research support, and disclosure of the authors' material financial relationships, if any, please see http://www.nber.org/chapters/c12693.ack.

Petroleum engineering provides an illustrative case study for assessing the dynamics of engineering labor markets more generally. Petroleum engineering is a field where concerns about shortages of talent have been strongly voiced by industry leaders for a number of years, first prompted by observations over the past decade of labor force demographics indicating a need for increased hiring. The anticipated wave of retirements in the industry, in a workforce where half of all geophysicists and engineers are expected to retire by 2018, is characterized by people in the oil and gas industry as "the great crew change." The demand for replacement hiring was further compounded by increased exploration that requires hiring additional petroleum engineers. The history of petroleum engineering demand reflects the cyclical demand for engineers in response to changes in the industry.

The building of the Trans-Alaska Pipeline and increased oil exploration in other regions led to rapidly increasing demand for petroleum engineers in the 1970s. But once the pipeline was built and new domestic oil exploration slowed, demand for new petroleum engineering graduates fell off. However, by the late 1990s many of the Trans-Alaska Pipeline generation engineers were approaching retirement age and, in the early 2010s, more of the workforce passed retirement age just as spikes in oil prices were leading to an anticipated increase in need for petroleum engineers as firms were motivated to explore more aggressively for new oil fields.

In this chapter, we first examine the recent history of claims that the market for engineers is dysfunctional. We then investigate the adjustment of the supply of engineering graduates to meet sharp increases in demand for petroleum engineers, and the implications for other areas of engineering and for the supply and demand of science and engineering (S&E) personnel. This investigation begins with a description of the field of petroleum engineering. We describe the field of petroleum engineering and supply responses to the market signals of the late 1990s and early in the first decade of the twenty-first century. We then discuss the mechanisms that signaled an upcoming demand spike to universities and other institutions, and the responses that allowed those institutions to meet the demand. We conclude with the implications of this case for the shortage and mismatch claims made about the S&E workforce.

8.2 Shortage and Mismatch Claims

Following the Great Recession of 2008, a group of technology company CEOs and others on the President's Council on Jobs and Competitiveness called for special measures by government, business, and universities to increase the number of U.S. engineering graduates by 10,000 a year (President's Council on Jobs and Competitiveness 2011). The Institute for Electrical and Electronics Engineering President Ron Jensen supported this call, asserting that more engineering graduates are needed because engineers drive innovation and create jobs (IEEE 2011). Companies cited a shortage of engineers as the reason they have "had" to move work offshore. CBS News featured Andrew Liveris, president of Dow Chemical, lamenting the scarcity of qualified engineers in the United States, saying this had caused his company to open research and development labs in Brazil, China, India, and Eastern Europe instead of the United States (CBS News 2011). And famously in 2011, Steve Jobs told President Obama that the reason he located 700,000 manufacturing jobs in China instead of the United States was his inability to find enough industrial engineers in the United States (Isaacson 2011; Salzman 2013, 59). These calls for government to increase the number of engineering graduates follow a decade-long series of reports and policy statements decrying shortages of science and engineering graduates.[1]

Some claim that persistent high rates of unemployment in the wake of the economic crisis that started in 2008 were caused by a mismatch between the skills of the unemployed and the skill needs of the new economy. Rapidly advancing technology implies that the skill needs of this "new" economy are primarily in the area of S&E human resources. These claims are compounded by the fear that the United States is losing (or will soon be losing) a technological race with other countries. This fear is supported by statistics showing that China and India produce hundreds of thousands of engineers.[2] Furthermore, numerous reports argue that the United States is losing technological competitiveness because of weaknesses in our K–12 math and science education system (see Salzman and Lowell [2008] and Lowell and Salzman [2007] for critique). One alleged consequence of this weakness is a shortage of Americans well enough educated to succeed in university engineering programs.[3]

These concerns have motivated proposals for heavy investments to remedy the weaknesses in the United States' K–12 math and science education system, make engineering as a career seem more attractive to young people (especially women and minorities who are underrepresented in engineering), offer more scholarships to engineering students, and expand university engineering programs. These primary and secondary educational reforms are typically complemented by proposals to bring in larger numbers of talented foreign engineers while retaining more of those who are already here at our universities and in our high-tech workforce.

1. For a history of STEM shortage claims, see Teitelbaum (2014) and Salzman (2013).

2. Although China and India, each with a population of over a billion people, do graduate many more engineers than the United States, the cited numbers have been found to overstate the actual numbers of bachelor's degree level engineers with globally competitive skills and, more importantly, reflect the domestic needs of those countries for their vastly greater demand than in the United States for infrastructure engineering; engineering infrastructure represents the largest share of demand for engineers in nearly all countries (Lynn and Salzman 2010).

3. The most prominent publications making these claims are probably those of the National Research Council (2007, 2010).

The purported need to increase the number of engineering graduates available in the United States for employers is based on a number of assumptions. It is assumed that there is indeed a shortage of engineers that cannot be met by the normal functioning of labor markets. Furthermore, it is assumed that the size of the stock of engineers in a country is proportional to the country's economic and military security, or even that to be secure a country must have more engineers than its rivals. Still another assumption is that increasing the supply of engineers, regardless of the demand expressed in the marketplace, will increase innovation and in turn drive economic growth. Still more assumptions underlie the proposals to fix the supposed shortage problem, such as the notion that part of the claimed shortage of engineering graduates is caused by the failure of American schools to train K–12 students so that they are qualified to enter university engineering departments, and this failure is exacerbated by a failure to convince students about the excitement of engineering as a profession. The contention, then, is that there are "market failures" leading to shortages in the supply of engineers in the United States. U.S. universities and students, according to this logic, are not responding to the national need for larger numbers of well-educated engineers, which requires the country to bring in larger numbers of talented foreign professionals and retain those who are here at our universities (Lynn and Salzman 2010).

Many labor market analysts have been skeptical of these claims, arguing that much of the push to train (or import) more engineers is actually motivated by the interests of employers in lowering labor costs rather than actual labor market dysfunctions. If there is a shortage of engineering graduates, companies can pay new graduates more, attracting additional engineers in the future and using market wages to allocate the existing workers to firms in greatest need. If there is no shortage, the costs to society of creating an oversupply of engineers are high. These include the wasted time and efforts of bright young people being trained for jobs that do not exist and the wasted resources of government and universities creating the capacity to train more engineers than are needed.[4] Moreover an extreme oversupply might dampen the interest of new generations of Americans in pursuing high-tech education, leading to real shortages in the future (Teitelbaum 2014, 118–54).

How responsive, generally, are labor markets to rapid changes in demand? Several studies have considered the labor market response to a large demand shock following the discovery of natural resources. This work typically finds evidence that labor markets are very responsive, although the response lags sharp initial wage increases. Indeed, recent natural resource booms such

4. Some of the reports and papers arguing for action to increase the number of engineering graduates in the United States are the Council on Competitiveness (2005), Farrell and Grant (2005), National Research Council (2007, 2012), and the National Association of Manufacturers (2005). We have addressed these arguments in Lowell and Salzman (2007), Lynn and Salzman (2010), Salzman (2013), and elsewhere.

as the building of the Trans-Alaska Pipeline (Carrington 1996) have been associated with higher labor supply elasticity than older cases such as the California Gold Rush (Margo 2000). There is also a literature that provides critical insights into the general equilibrium response to a natural resource shock (e.g., Marchand 2012; Clay and Jones 2008; Aragon and Rud 2013; Black, McKinnish, and Sanders 2005) that considers the broader labor market rather than engineering per se.

So far, evaluations of arguments about alleged market failures in engineering job markets have generally relied on research showing the numbers of graduates each year who are hired into engineering jobs, university enrollments, salary trends, and other statistical indicators for engineers in the aggregate. Dynamic changes in a specific labor market are more difficult to study, yet such studies are needed to give us a better sense of what influences the supply of engineers (Meiksins and Smith 1996). How quickly does the education system, for example, respond to changes in market demand? Do shortages of qualified engineering students or institutional rigidities in universities cause failures in supply to meet the demand for engineers? Let us now turn to the case of the market response to sudden changes in the demand for petroleum engineers.

8.2.1 Petroleum Engineering: What Do Petroleum Engineers Do?

Petroleum engineers are engaged in a wide range of activities related to the development and exploitation of crude oil and natural gas fields. Their activities span the life cycle of the fields: finding reservoirs, deciding how to get the best yield from them, designing equipment for drilling and pumping, ensuring regulatory compliance, getting additional yield from older fields, and shutting down depleted fields. Major areas of specialization within petroleum engineering include drilling engineering, production engineering, reservoir engineering, and petrophysical engineering (designing tools and techniques to determine rock and fluid characteristics). Engineers from mechanical, civil, electrical, geological, and chemical engineering have contributed to these fields. The *Princeton Review* (2013) says the work "can mean travel, long stays in unusual (and sometimes inhospitable) locations, and uncertain working conditions." The Review cites a petroleum engineer as saying, "If you're into engineering and gambling, petroleum engineering is for you." Because of the sometimes harsh working conditions and sometimes quickly fluctuating employment, prospects' starting salaries have tended to be high compared to other fields of engineering. While a bachelor's degree in petroleum engineering is preferable for petroleum engineers, some hold degrees in mechanical or chemical engineering (Bureau of Labor Statistics 2014).

The profession of petroleum engineering got its formal start early in the twentieth century when it became clear that the harvesting of surface oil and the use of water well-drilling techniques were not sufficient to meet the burgeoning demand for oil and gasoline. The first oil fields were in Pennsylvania, and the University of Pittsburgh introduced courses in oil and gas industry practices in 1910. The first degree in petroleum engineering was granted in 1915. The University of California at Berkeley introduced courses in petroleum engineering around the same time, and established a four-year petroleum engineering program in 1915. Around twenty universities now offer petroleum engineering education programs; the largest programs (in number of bachelor of science degrees awarded in recent years) are Texas A&M University, Pennsylvania State University, Colorado School of Mines, University of Texas at Austin, and Texas Tech University. A number of programs at other universities have not awarded degrees in recent years, and some programs have capped enrollments. Some companies offer in-house training programs in petrochemical engineering.

At first the focus of petroleum engineers was on finding ways to address drilling problems. In the 1920s it shifted to improving well design and production methods. A decade later, a major concern was finding ways to maximize outputs from entire fields. After World War II, petroleum engineers improved the techniques of reservoir analysis and petrophysics (American Petroleum Institute 1961). New technology also was needed to support the new offshore oil industry. More recently, additional challenges have been posed by the desire to find oil and natural gas in the arctic, very deep water, and desert conditions. These have required additional technical inputs from thermohydraulics, geomechanics, and intelligent systems. Still another development has been the increased use of hydraulic fracking techniques for the extraction of hydrocarbons.

This chapter draws on two data sources to assess the size of the petroleum engineering workforce: the American Community Survey (ACS), produced by the Census Bureau (Ruggles et al. 2017), and the Occupational Employment Statistics (OES), produced by the Bureau of Labor Statistics (1996, 1998, 2004, 2006, 2010, 2014).[5] In 2013 there were about 35,000 petroleum engineers in the United States (37,340 according to the ACS and 34,910 according to the OES; see figure 8.2). The ACS estimates show a 58 percent increase from the 23,604 petroleum engineers in the workforce in 2003. Employers include major oil companies and oil-industry suppliers such as Exxon-Mobil, Chevron, Haliburton, and Schlumberger, as well as large numbers of smaller independent oil, services, and production companies. In 2015 the mean salary for petroleum engineers in the United States was estimated to be $135,985 (in 2016 USD) according to the ACS and $151,477 according to the OES data sets. Median salaries were somewhat lower in both data sets at $106,325 and $131,630, respectively.

In the number of bachelor's degrees awarded, petroleum engineering is

5. The ACS is a population survey (workers), while the OES is based on employer surveys, which may result in diverging estimates due to sampling and occupational/industry definitional differences, as well as response differences between workers and employers (Abraham et al. 2013).

one of the smaller engineering fields. In 2014–2015, only 1,688 bachelor's degrees of 87,812 bachelor's degree awards in engineering in the United States were petroleum engineers. Nearly half the bachelor's degrees awarded in engineering went to students in just three fields: mechanical (25 percent), civil (18 percent), and electrical (21 percent). In 2012–2013, some 14 percent of new petroleum engineers were women, slightly less than the 19 percent of women in engineering overall. The number of bachelor's degrees awarded in petroleum engineering more than quintupled from 2003 to 2015, from 252 to 1,383. Petroleum engineering has the largest rate of increase of any engineering field, though the even smaller workforces in mining engineering and nuclear engineering also had large rates of increase.[6]

8.3 Market Signals and Market Responses

In the 1970s, the building of the Trans-Alaska Pipeline and increased oil exploration in other regions led to rapidly increasing demand for petroleum engineers. By 2002 however, *Occupational Outlook* forecast an employment decline "because most of the petroleum-producing areas in the United States already have been explored" (Bureau of Labor Statistics 2004), and this continued to be the forecast through the 2008 edition of *Occupational Outlook*. In the 2014–2015 edition, however, the Bureau of Labor Statistics forecast for 2012–2022 changed to a projected employment increase of 26 percent over the coming decade because "petroleum engineers increasingly will be needed to develop new resources, as well as new methods of extracting more from existing sources." The shift to greater exploration followed the 2008 oil price spike, which also increased the returns to investments in types of oil extraction that were previously cost prohibitive (e.g., horizontally drilled and hydraulically fractured shale), thus increasing the demand for petroleum engineers, especially those with new skill sets. Following this period of rapid expansion, oil prices and employment fell, and growth moderated. The 2014–2024 projections, in the 2016–2017 edition of the *Occupational Outlook*, were substantially lower, forecasting a more modest 10 percent growth over the period, with the petroleum engineering employment having fallen from 38,500 in 2012 to 35,100 in 2014.

The number of job openings began to exceed the number of graduates around 2002, even though there still had been no overall workforce growth.[7] This was because of retirements and because there had been little hiring since the earlier oil boom and hiring expansion of the 1970s and 1980s. In

6. Although no other field quadrupled, mining engineering went from 85 to 231, and nuclear engineering went from 202 to 614 from 2004 to 2013 (Yoder 2013).

7. The BLS's *Occupation Outlook Handbook* in 2002 noted that "Employment of petroleum engineers is expected to decline through 2010 because most of the potential petroleum-producing areas in the United States already have been explored. Even so, favorable opportunities are expected for petroleum engineers because the number of job openings is likely to exceed the relatively small number of graduates. All job openings should result from the need to replace petroleum engineers who transfer to other occupations or leave the labor force."

interviews with managers in oil companies, we found high levels of concern because the large cohort of engineers hired in the 1970s and 1980s was retiring just as the firms were launching large development and maintenance projects. This underlying demand was then exacerbated by the oil price spike, which intensified exploration efforts, as higher oil prices made previously unprofitable exploration (which in many cases posed greater engineering challenges) now profitable.

The response to this confluence of events—little hiring for many years, a current workforce that was aging and retiring, and a sudden increase in oil exploration—led to an observable demand for new petroleum engineers that exceeded the number of graduates each year. The earlier demand pressure from retirements had already led to increases in starting salaries, but with the oil-price spike petroleum engineering starting salaries rose even further, becoming the highest of all fields of engineering for new bachelor's degree graduates (National Association of Colleges and Employers 2010). Starting salaries (in 2014 dollars) jumped from an already high \$65,024 in 1997 to \$72,485 in 1999 and then rose to \$73,029 and \$75,598 in 2003 and 2005, respectively, only to fall to \$73,711 in 2008 (Bureau of Labor Statistics 2004, 2006; National Association of Colleges and Employers 2009). The 2010s increase in demand for petroleum engineering graduates began in 2009, when real starting salary offers jumped to \$91,275 and steadily increased afterward, reaching a peak of \$99,111 in 2013 (National Association of Colleges and Employers 2010, 2014). In all these years, petroleum engineering salaries were higher than other engineering salaries but, until the spike in demand, the petroleum engineering starting salary premium was relatively small. For example, the 1997 \$43,674 starting salary for petroleum engineers was only slightly greater than that for the second-highest-paid engineering field, chemical engineers, who received an average starting salary of \$42,817. In 2010, however, the nominal starting salary of \$86,220 for petroleum engineers was much higher than that of the second-highest field, still chemical engineering, which was only \$65,142 (National Association of Colleges and Employers 2010). Petroleum engineer starting salary figures from the National Association of Colleges and Employers (NACE) are reported in figure 8.1, along with mean salary trends for all petroleum engineers estimated using the ACS and the OES database (all in 2016 dollars). Starting salary data from NACE should be interpreted with some caution as they are not comprehensive, but are based on a survey of only NACE-member employers and a small sample of petroleum engineers. However, the trends in starting salaries track trends in the salaries of all petroleum engineers, increasing impressively over the last decade. From 2003 to 2013, petroleum engineer starting salaries reported by NACE and mean petroleum engineer salaries reported in the OES both grew by over 35 percent. The ACS reports somewhat slower mean salary growth of just under 25 percent.

Employment growth between 2003 and 2013 was even more substantial

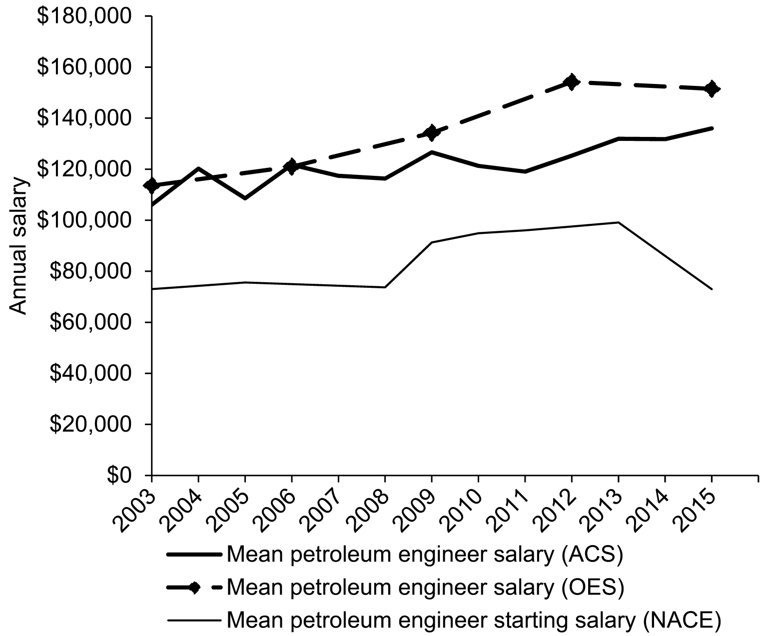

Fig. 8.1 Mean real petroleum engineer salaries and starting salaries, 2003–2015
Source: Authors' calculations from annual NACE salary surveys, BLS Occupational Employment Statistics, and the American Community Survey. Starting salaries for 2004, 2006, 2007, and 2012 were not available and have been linearly interpolated. The OES data are three-year moving averages; only one data point in each three-year series is plotted.

than earnings growth. Figure 8.2, which presents data on petroleum engineer employment and the number of foreign petroleum engineers working in the United States and petroleum engineer employment from the OES, shows that employment grew even more rapidly between 2003 and 2013 than earnings. The ACS reports a 58 percent increase in petroleum engineer employment over this decade while the OES reports a 200 percent increase. The major reason for the difference in percentage change is a large difference in the estimated 2003 employment due, we believe, to the relatively small samples used to estimate national employment levels, and the OES uses a three-year moving average, which is a lagged estimate of annual growth.[8] Nevertheless, the data sources consistently show substantial growth from a workforce of around 20,000 to one of around 35,000 (recent surveys from ACS and OES show similar estimates of workforce sizes in 2013 and then diverge dramatically after 2013, likely due to ACS survey differences; the

8. In the ACS, only several hundred survey respondents report working as petroleum engineers each year.

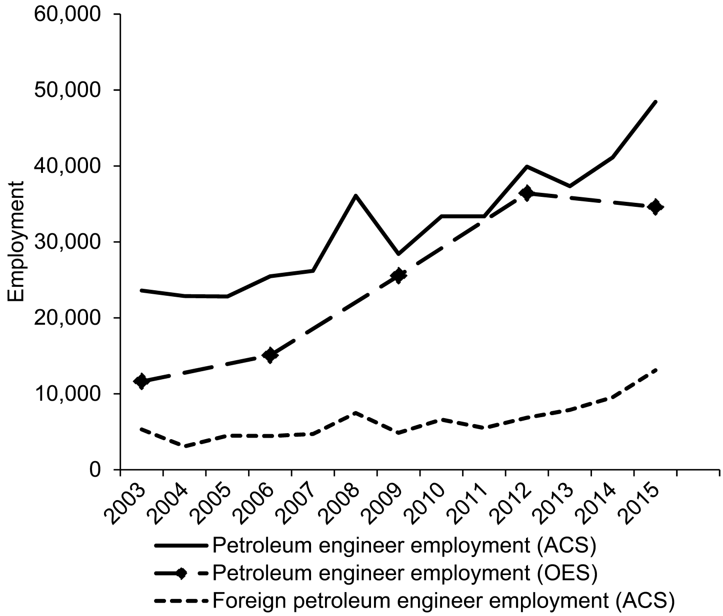

Fig. 8.2 Petroleum engineer employment, 2003–2015

Source: Authors' calculations from the BLS Occupational Employment Statistics and the American Community Survey. The OES data are three-year moving averages; only one data point in each three-year series is plotted.

large differences in the two surveys mentioned above are for earlier years).[9] The increase in the number of foreign (i.e., noncitizen) petroleum engineers during this period in the ACS was somewhat slower than the growth in number of all petroleum engineers (48 percent growth compared to 58 percent).

Rapid growth in the employment of petroleum engineers generally came by hiring younger workers. Figure 8.3 shows the change in the age distribution of the workforce in 2003 and the age distribution in 2013. While the

9. The OES is an establishment survey using annual estimates that are a moving average of the previous three years, whereas the ACS is a household survey. The sharp divergence in employment after 2013 may be the result of survey and methodological differences between the two surveys but, we postulate, also could be an artifact of the decline in regular industry employment. As an establishment survey, the OES reports wage employment of petroleum engineers engaged in engineering activities by firms; increases in retirements, layoffs, and contract hiring would lead to lower OES but not lower ACS employment reporting if those leaving firms become consultants or contract workers, and particularly if they are hired as management consultants rather than performing specific engineering tasks (personal communication with OES staff, June 20, 2017). Moreover, to the extent that incumbent and older workers retire or are laid off at a greater rate than employment of younger workers, and become consultants or contract workers, and/or younger workers are hired as contract workers or through staffing firms, this would lead to an increase in overall employment of "petroleum engineers" in population surveys but a decline in firm-based employment numbers. The OES data are consistent with the numerous reports from universities and firms about employment patterns (SPE 2015; Weaver 2017; Gallucci 2016).

Fig. 8.3 Petroleum engineer age distribution, 2003 and 2013
Source: Authors' calculations from the American Community Survey.

modal age of petroleum engineers in 2003 was just under fifty, by 2013 it was under thirty. Although some of these new employees could have been pulled in from other sectors of the economy, many are new graduates of petroleum engineering programs and other engineering programs such as chemical engineering, which exhibited considerable growth over this period.[10]

The changes in earnings and employment between 2003 and 2013 suggest *a tremendous responsiveness of employment to wages*, with an implicit elasticity of 2.4 from the ACS and 5.7 from the OES data.[11] Perhaps because petroleum engineering is a relatively small occupational group, it shows a response of this magnitude to price signals, as even a modestly sized absolute change has a large proportionate effect.

In response to increasing median salaries, starting salaries, and other market signals, the number of new petroleum engineering bachelor's degrees awarded by U.S. universities more than quintupled between 2003 and 2015. Most of the growth was concentrated between 2008 and 2011, at the same time that the strongest starting-salary growth was occurring. During this period, petroleum engineering bachelor's awards grew from 521 to 1,030.

10. A degree in mechanical or chemical engineering may also suffice for employment as a petroleum engineer according to the *Occupational Outlook Handbook* (Bureau of Labor Statistics 2014).

11. While these figures strongly indicate a responsive labor market, the exact point estimates should be interpreted with considerable caution. Changes in employment and earnings over the course of ten years suggest that these are relatively long-run elasticities, which are expected to be higher. They also pertain to a small workforce, for which rapid growth is easier to accommodate. Finally, the elasticity estimates are clearly imprecise and vary considerably across data sources.

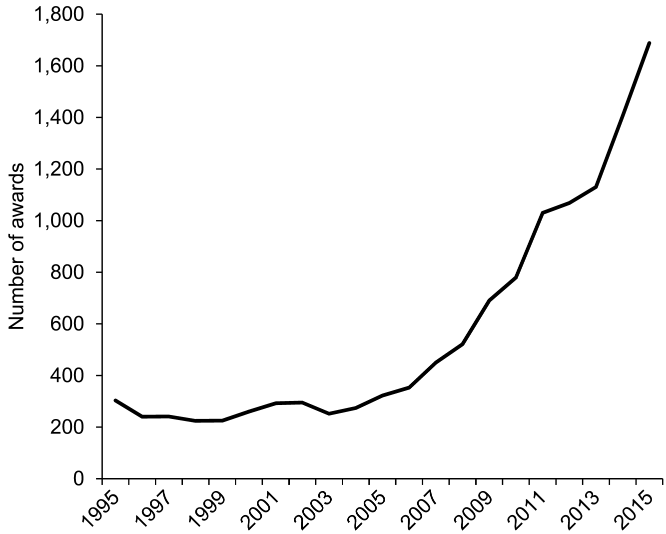

Fig. 8.4 Bachelor's degrees awarded in petroleum engineering, 1995–2015
Source: Authors' calculations from the IPEDS.

Texas A&M and Colorado School of Mines more than tripled their output of new graduates from 42 to 128 and 32 to 100, respectively. As shown in figure 8.4, the dramatic increase in petroleum engineering bachelor's degrees awarded followed the rise in starting salaries, which in turn reflected an increase in industry demand. This would seem to be a clear textbook case of efficient and responsive market functioning. It seems to show that normal market mechanisms, namely wage increases, can dramatically and quickly increase supply.

8.4 Dependencies on Domestic- or Foreign-Student Supply

A key claim about the U.S. S&E workforce is that it is dependent on foreign students and workers because it is not possible to find sufficient numbers of U.S. S&E workers. However, when we examine the dramatic increase in petroleum engineering graduates we find, interestingly, that although a significant source of supply for petroleum engineers historically has been foreign students, the new demand accompanied by sharp increases in salaries resulted in markedly increased numbers of domestic students (U.S. citizens and permanent residents) responding to these market signals and graduating in petroleum engineering. In the initial stages of increased hiring and large salary increases, in the middle of the first decade of the twenty-first century, nearly the entire increase in graduates was composed of U.S. students (citizens and permanent residents), and the share of foreign students declined.

Toward the end of the decade, the number and share of foreign students increased, but this was also a period when salary growth began to slow and even plateau. The share of petroleum engineers who were foreign born ranged between 16 percent and 21 percent during the period of strong wage and employment growth, and then increased sharply after 2012 as annual wage and employment growth weakened or declined. As will be discussed below, some petroleum engineering department chairs are now expressing concerns about an impending oversupply of new graduates.

In terms of understanding responsiveness of engineering labor markets, it is important to note that it is not just the overall supply of petroleum engineering graduates from colleges that appears to have been responsive to demand and wages, but it is the *domestic supply in particular* that supplies the increased pool of graduates. As wages increased and job demand in the United States increased, there has been a shift in the relative share of domestic students in the graduating pool. The percentage of foreign petroleum engineering graduates in the United States on student visas, the highest of any of the engineering fields at the bachelor's degree level, declined from a peak of 34 percent in 2005 to 24 percent in 2013 as the domestic supply increases (figures 8.5 and 8.6). At the bachelor's degree level, the

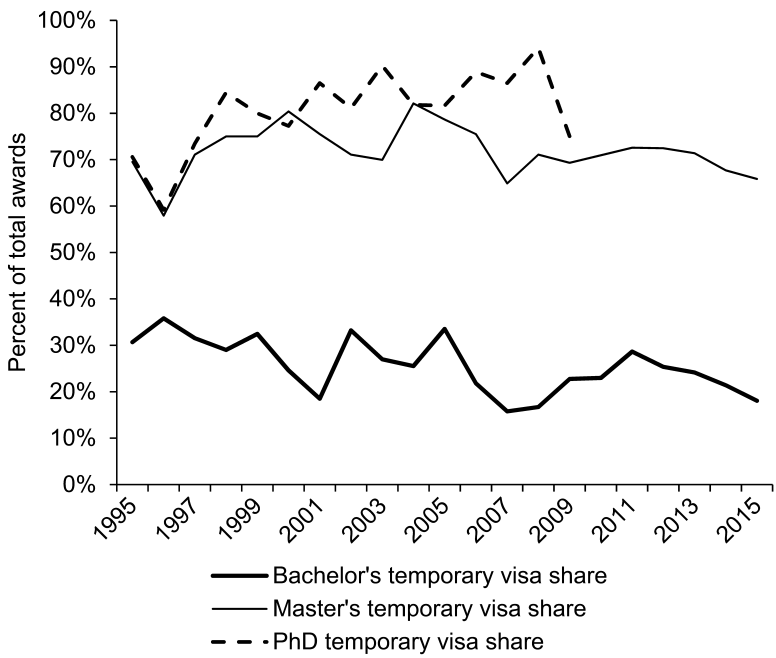

Fig. 8.5 Temporary visa share of degrees awarded in petroleum engineering, 1995–2015

Source: Authors' calculations from the IPEDS.

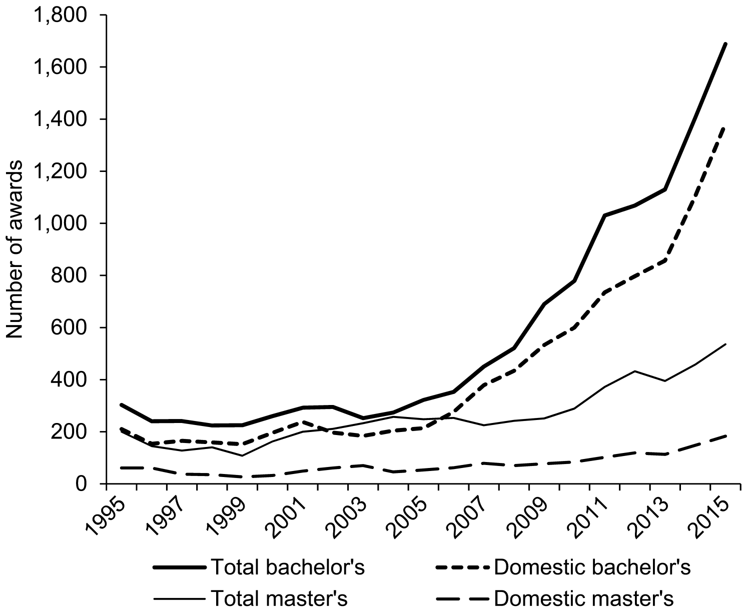

Fig. 8.6 Petroleum engineering degree awards by temporary visa status, 1995–2015

Source: Authors' calculations from the IPEDS.

percent of total graduates who are on student visas dropped to the lowest proportion of total graduates in almost twenty years in 2007, at the beginning of the rapid increase in bachelor's awards. In the initial period of sharp salary and hiring increases, the share of graduates on student visas dropped from slightly more than half the proportion twelve years earlier, and the increased demand was largely satisfied by American students (foreign students accounted for 31 percent of the graduates in 1995 vs. 17 percent in 2007, as the increase came from U.S. students while the number of student visa graduates held steady).

8.4.1 When Demand for Engineers Drops

As was noted above, one reason for the higher salaries received by petroleum engineers is the instability of job markets (*Princeton Review* 2013). When oil prices drop it becomes uneconomical to explore and exploit fields where production costs are high (such as deepwater offshore sites, or those requiring expensive new technologies).[12] As oil prices sharply declined in

12. The relationship is not entirely linear, because petroleum projects differ in the time required for completion. Onshore projects such as exploration through first production can be relatively quick, while deepwater offshore projects can take years before first production.

2014 and early 2015 there were increasing reports of job cuts, either those that had already occurred or those that were feared. In February 2015, Reuters stated that more than 100,000 layoffs worldwide had been reported in the oil industry. Halliburton had announced cuts of 8 percent of its global workforce and Schlumberger was planning to eliminate 7 percent of its workforce (Kemp 2015). The Society of Petroleum Engineers' survey found only two-thirds "of 2015 U.S. petroleum engineering bachelor's degree graduates have found jobs in the oil and gas industry, compared with 95 percent in 2014 and 97 percent in 2012" (SPE 2015). The *Occupational Handbooks* show the petroleum engineering workforce fell from 38,500 in 2012 to 35,100 in 2014.

Bloomberg (Shauk 2015) reported concerns of new petroleum engineering graduates about their job prospects commenting, "Six months ago, a degree in petroleum engineering was a ticket to a job with a six-figure salary. Now it's looking like a path to the unemployment office." The director of undergraduate advising for Texas A&M's Petroleum Engineering Department indicated that students were expressing "definite concern" about the job market.

In March 2015, we sent survey questions to the chairs of thirteen leading U.S. petroleum engineering departments asking about their experiences in adjusting capacity to meet industry demands for new petroleum engineering graduates. Three of the four chairs who responded expressed concerns that U.S. universities had overbuilt their capacity and needed to take stronger actions to control growth so as to avoid a glut of new graduates. The fourth chair was more sanguine, expressing confidence that the demand for petroleum engineers would continue growing so that the increased capacity would be needed.

Despite the recent downturn, industry spokesmen have also continued to argue that large numbers of petroleum engineers will be needed in the next few years. Not discussed, however, was how programs and students should respond in the short term if there are not immediate employment opportunities for current graduates.

8.5 Implications and Conclusions

The case presented here suggests that American universities and American students were highly responsive to market signals when it came to addressing the need for new graduates in petroleum engineering. But was the market responsive "enough"? Conceivably, even bigger increases than the doubling and tripling that occurred would have been desirable. Or perhaps quality standards were dropped in an effort to meet the increased demand. While a systematic analysis of these issues goes beyond the scope of this chapter, the following "Industry Alert" from the Society of Petroleum Engineers (SPE) in 2010 is suggestive.

> Environmental and remediation companies of all sizes have a real opportunity to take steps in 2010 to address that shortage of engineering talent expected in the next decade, especially in the United States and Europe.
>
> Key factors that are creating this opportunity:
>
> *An increase in the number of graduates in petroleum engineering programs is creating the largest pool in 20 years of young engineers seeking entry into the oil and gas industry.
>
> *The global recession has caused experienced professionals to postpone retirement, offering a window of opportunity to transfer their knowledge to these new entrants.
>
> *These students can contribute very quickly, and companies that act now can begin developing new entrants into autonomous professionals with the complex decision-making and ability required to exploit advanced technology.
>
> *Scaling back on new graduate recruiting in 2010 could lead to a permanent loss of this talent from the industry, and chill the interest of future engineering students in pursuing careers in the oil and gas industry. (Rubin 2010)

This strongly suggests that even in a peak demand year there was no serious shortage in the availability of new petroleum engineering graduates and that, indeed, there was some concern of future generations being turned away from the field if companies did not proactively hire more new graduates than were immediately needed. The petroleum engineering department chairs responding to our survey seem to confirm this impression.

The potential downside of large increases in the supply of engineers is suggested in a guest editorial written by the current department chair and a former department chair of the Petroleum Engineering Department at Texas A&M University. These authors note:

> Between fall 2011 and fall 2012, the number of freshmen in petroleum engineering programs in the United States grew from 1,388 to 2,153, a 55 percent increase in one year. The enrollment pressure we are experiencing at Texas A&M suggests that there will be another increase in freshman enrollment in 2013. We are rapidly heading toward having more than 2,000 bachelor of science degree petroleum engineering graduates per year in the United States. So far, essentially all of our graduates have been receiving job offers, but there is concern that the job market may not grow as fast as enrollment and graduation rates. (Hill and Holditch 2013)

These authors note similarities with an earlier ramping up of the number of petroleum engineering students in the 1980s (though they say that if account is taken of the number of students transferring into petroleum engineering in their sophomore and junior years, the increases are even larger this time). They fear a potential collapse of the job market and suggest that more universities should manage "the unbounded growth in enrollment that is currently occurring." They note that the two departments that have historically been the largest in the United States, Texas A&M University and University of Texas at Austin, have indeed controlled their growth, but complain that other departments have not, and have passed the two Texas schools in size of enrollments. Mississippi State University, for example, reinstated its petroleum engineering program in 2014, having suspended it in 1995, and its Fall 2015 enrollment of sixty-seven far exceeded expected enrollment of twenty-five, just as the job market began its decline (Weaver 2017; Lassetter 2014).

So might there still somehow be an impending crisis demanding special measures to increase the number of graduating engineers in petroleum engineering? Employers continue to voice alarm, but some suggest that in the past such warnings were overstated. Rigzone, a website that posts job notices in the petroleum industry, for example, said in a 2011 article that the "great crew change" is indeed a problem, but comments, "Much like the old story about the boy who cried 'wolf' so many times that nobody would listen when the wolf finally was at the door, statistics confirm that the post–World War II 'baby boom' generation is at the retirement door" (Saunders 2011).

What then, does the case of petroleum engineers suggest about other fields of engineering? First, in petroleum engineering there seemed to be no serious difficulty in getting qualified students once students had the strong incentive of high salaries to enter this field of engineering. Was this because qualified students were drawn from other fields leaving them short of qualified students? While it is difficult to totally dismiss this possibility, we have seen no sign of it in the literature or in discussions with people in the field. The four chairs of leading petroleum engineering departments who responded to an email survey sent out in March 2015 indicated that they have experienced no difficulty in recruiting students. While the department chairs complained of having some difficulties in recruiting as many qualified faculty as they might have liked (this need was met by hiring more practitioners with industry experience), they were able to meet the increases in demand for qualified students, with no lowering of standards. U.S. universities seem to have been remarkably flexible. Third, and perhaps most important, it is not clear that nonmarket signals such as projections of demand by experts (U.S. Department of Labor) or industry spokespeople (who may, after all, have a vested interest in talking up prospects for demand), have done any better in their predictions than the market.

In the case of petroleum engineering we saw no signs of problems caused by weaknesses in the U.S. K–12 education system or the motivation of young people to undertake careers in engineering. It seemed, as well, that the United States was reasonably able to meet its needs for S&E workers through domestic student supply. It is important to note that this analysis of the responsiveness of student supply to market signals does not address issues such as diversity and the underrepresentation of groups such as women and some minorities. Research suggests that, in the area of diversity, the market is not effective and thus a need may exist for programs that increase the interest of minorities and women in some of the STEM careers, and their access to some fields of STEM education (women are the majority of life science majors and have been near parity in the mathematics bachelor's degrees for the past forty years). Nor do we advocate the exclusion of talented foreign STEM workers from the U.S. economy. The findings of this analysis, however, suggest that when it comes to providing an appropriate number of engineers in the United States, the U.S. education system and job market have been highly responsive economic forces, not the failures that alarmists have habitually portrayed.

References

Abraham, K. G., J. Haltiwanger, K. Sandusky, and J. R. Spletzer. 2013. "Exploring Differences in Employment between Household and Establishment Data." *Journal of Labor Economics* 31 (5): S129–72.

American Petroleum Institute. 1961. *History of Petroleum Engineering*. New York: American Petroleum Institute.

Aragon, Fernando, and Juan Pablo Rud. 2013. "Natural Resources and Local Communities: Evidence from a Peruvian Gold Mine." *American Economic Journal: Economic Policy* 5 (2): 1–25.

Black, Dan, Terra McKinnish, and Seth Sanders. 2005. "The Economic Impact of the Coal Boom and Bust." *Economic Journal* 115 (503): 449–76.

Bureau of Labor Statistics. 1996. *Occupational Outlook Handbook, 1996–97, UM-St. Louis Libraries ed.*, derived and modified by Raleigh Muns July 20, 1996. http://stats.bls.gov/ocohome.htm.

———. 1998. *Occupational Outlook Handbook, 1998–99, UM-St. Louis Libraries ed.*, derived and modified by Raleigh Muns Apr. 14, 1998. http://stats.bls.gov/ocohome.htm.

———. 2004. *Occupational Outlook Handbook, 2004–05 ed.* Accessed July 15, 2017. http://www.bls.gov/oco/ocos027.htm.

———. 2006. *Occupational Outlook Handbook, 2006–07 ed.* Accessed July 15, 2017. http://www.bls.gov/oco/ocos027.htm.

———. 2010. *Occupational Outlook Handbook, 2010–11 ed.: Engineers*. Accessed July 15, 2017. http://www.bls.gov/oco/ocos027.htm.

———. 2014. *Occupational Outlook Handbook, 2014–2015 ed.* Accessed July 15, 2017. http://www.bls.gov/oco/ocos027.htm.

Carrington, William. 1996. "The Alaskan Labor Market during the Pipeline Era." *Journal of Political Economy* 104:186–218.

CBS News. 2011. "U.S. Not Producing Enough Engineers." June 14. https://www.cbsnews.com/videos/us-not-producing-enough-engineers/.

Clay, Karen, and Randall Jones. 2008. "Migrating to Riches? Evidence from the California Gold Rush." *Journal of Economic History* 68 (4): 997–1027.

Council on Competitiveness. 2005. *Innovate America: Thriving in a World of Challenge and Change*. Washington, D.C.: Council on Competitiveness.

Farrell, Diana, and Andrew Grant. 2005. "China's Looming Talent Shortage." *McKinsey Quarterly* 4:72.

Gallucci, Maria. 2016. "As US Oil Industry Jobs Decline, Undergraduates Are Ditching Petroleum Engineering Degrees." *Inside Business Times*, Mar. 18. http://www.ibtimes.com/us-oil-industry-jobs-decline-undergraduates-are-ditching-petroleum-engineering-2338662.
Hill, Daniel, and Stephen A. Holditch. 2013. "Guest Editorial: Déjà Vu All Over Again." *Journal of Petroleum Technology* 65 (6).
IEEE (Institute of Electrical and Electronics Engineers). 2011. "New IEEE-USA President Looks to Advance US Innovation and Entrepreneurship." *IEEE Antennas and Propagation Magazine* 53 (1): 196.
Isaacson, Walter. 2011. *Steve Jobs*. New York: Simon & Schuster.
Kemp, John. 2015. "Mass Layoffs Complicate Oil Industry's Long-Term Plans: Kemp." *Reuters*, Feb. 16. http://www.reuters.com/article/oil-employment-graduates-kemp-idUSL5N0VN2ZN20150213.
Lassetter, Susan 2014. "Mississippi State to Offer State's Only Petroleum Engineering Degree." Mississippi State University College of Engineering, Nov. 20. Accessed June 20, 2017. http://www.bagley.msstate.edu/news/mississippi-state-to-offer-states-only-petroleum-engineering-degree/.
Lowell, B. Lindsay, and Hal Salzman. 2007. "Into the Eye of the Storm: Assessing the Evidence on Science and Engineering Education, Quality, and Workforce Demand." Paper presented at the annual meeting of the Association for Public Policy Analysis and Management, Washington, D.C., Nov. 8–10.
Lynn, L., and H. Salzman. 2010. "The Globalization of Technology Development: Implications for U.S. Skills Policy." In *Transforming the U.S. Workforce Development System: Lessons from Research and Practice*, edited by David Finegold, Mary Gatta, Harold Salzman, and Susan J. Shurman, 57–86. New York: Labor and Employment Relations Association.
Marchand, Joseph. 2012. "Local Labor Market Impacts of Energy Boom-Bust in Western Canada." *Journal of Urban Economics* 71 (1): 165–74.
Margo, Robert A. 2000. *Wages and Labor Markets in the United States, 1820–1860*. Chicago: University of Chicago Press.
Meiksins, P., and C. Smith. 1996. *Engineering Labor: Technical Workers in Comparative Perspective*. London: Verso.
National Association of Colleges and Employers. 2009. *Salary Survey*, vol. 48, iss. 2. Bethlehem, PA: NACE.
———. 2010. *Salary Survey*, vol. 49, iss. 3. Bethlehem, PA: NACE.
———. 2014. *Salary Survey*. Bethlehem, PA.
National Association of Manufacturers. 2005. *The Looming Workforce Crisis: Preparing American Workers for 21st Century Competition*. Washington, D.C.: National Association of Manufacturers.
National Research Council. 2007. *Rising above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*. Washington, D.C.: National Academies Press.
———. 2010. *Rising above the Gathering Storm, Revisited: Rapidly Approaching Category 5*. Washington, D.C.: National Academies Press.
———. 2012. *Assuring DoD a Strong Science, Technology, Engineering, and Mathematics (STEM) Workforce*. Washington, D.C.: National Academies Press.
President's Council on Jobs and Competitiveness. 2011. "President's Council on Jobs and Competitiveness Announces Industry Leaders' Commitment to Double Engineering Internships in 2012." Press release, Aug. 31. https://obamawhitehouse.archives.gov/the-press-office/2011/08/31/president-s-council-jobs-and-competitiveness-announces-industry-leaders.
Princeton Review. 2013. "Career: Petroleum Engineer." Accessed Feb, 2013. http://www.princetonreview.com/careers.aspx?cid=109.

Rubin, Mark. 2010. "Workforce Dilemma Requires Action." *American Oil & Gas Reporter*, Mar. 20. http://www.aogr.com/index.php/magazine/editors_choice/march_2010_ed.

Ruggles, Steven, J. Trent Alexander, Katie Genadek, Ronald Goeken, Matthew B. Schroeder, and Matthew Sobek. 2017. Integrated Public Use Microdata Series: Version 7.0 [Machine-readable database]. Minneapolis: University of Minnesota.

Salzman, Hal. 2013. "What Shortages? The Real Evidence about the STEM Workforce." *Issues in Science and Technology* (National Academy of Science policy magazine) 29 (4). http://issues.org/29-4/what-shortages-the-real-evidence-about-the-stem-workforce/.

Salzman, Hal, and Lindsay Lowell. 2008. "Making the Grade." *Nature* 453:28–30.

Salzman, Hal, and Leonard Lynn. 2010. "Engineering and Engineering Skills: What's Really Needed for Global Competitiveness." Paper presented at the annual meeting of the Association for Public Policy Analysis and Management, Boston, MA, Nov. 4.

Saunders, Barbara. 2011. "The Great Crew Change: 'Wolf Cries' or Reality?" *Rigzone*, Aug. 12. Accessed Aug. 12, 2011. http://www.rigzone.com/news/article.asp?a_id=110134.

Shauk, Zain. 2015. "Is There Money to Be Made in Oil? New Grads Don't Think So." Accessed Jan. 28, 2015. http://www.bloomberg.com/news/articles/2015-01-29/graduates-question-six-figure-oil-jobs-as-layoffs-swell.

Society of Petroleum Engineers (SPE). 2015. "Fewer Petroleum Engineering Graduates Finding Jobs in Industry." Accessed June 20, 2017. http://www.spe.org/news/article/fewer-petroleum-engineering-graduates-finding-jobs-in-industry.

Teitelbaum, Michael S. 2014. *Falling Behind? Boom, Bust, and the Global Race for Scientific Talent*. Princeton, NJ: Princeton University Press.

Weaver, Andrew. 2017. "Chemical and Petroleum Engineering: The Numbers." Mississippi State University College of Engineering. Accessed June 20, 2017. http://www.che.msstate.edu/chemical-and-petroleum-engineering-the-numbers/.

Yoder, Brian L. 2013. "Engineers by the Numbers." American Society for Engineering Education. https://www.asee.org/papers-and-publications/publications/college-profiles/15EngineeringbytheNumbersPart1.pdf.