Dynamics of engineering labor markets: petroleum engineering demand and responsive supply

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U.S. ENGINEERING
IN A GLOBAL ECONOMY

Edited by Richard B. Freeman
and Hal Salzman
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From the late 1950s—when the launch of Sputnik produced fears that the United States was losing its technological leadership to the Union of Soviet Socialist Republics (USSR)—to the present, the state of the labor market for specialists in STEM (science, technology, engineering, and mathematics) occupations has attracted considerable public attention, spurring analysis in workforce development, labor economics, and economics more broadly. Public concern historically has focused on possible shortages of scientists and engineers hampering economic growth or national security. The National Bureau of Economic Research (NBER) has a long history of analyzing the science and engineering workforce, beginning with Blank and Stigler’s (1957) *The Demand and Supply of Scientific Personnel*, which came in the same year of the Sputnik launch. While the title referred to scientific personnel, most of the book dealt with the engineering profession. This is not surprising since the vast majority of STEM workers in industry were, at that time, engineers. Today, the expansion of the biomedical workforce and of computer science and other information technology (IT) workers has overtaken the numeric dominance of engineering among STEM workers, but engineering remains a critical part of scientific personnel in industry and the largest number of STEM workers in many industries.

The central issue in the labor market analysis of engineers following Sputnik...
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The meaning of a shortage in a flexible market economy where wages and prices move freely to clear supply and demand. When demand for labor rises relative to supply, wages rise and the supply increases, so what exactly is a shortage? Arrow and Capron (1959) treated shortages as the result of rapid shifts in demand, such as the huge increase in demand for engineers, physicists, and others sparked by the U.S. effort to surpass the USSR in space technology. Freeman (1971) put the supply and demand responses together into a cobweb model in which cyclical fluctuations in wages, employment, and enrollments arise naturally from the lag in supply responses, due to the years students spend learning STEM skills. Engineering was the prime exemplar of this pattern.

In the 1980s and 1990s, NBER work by Zvi Griliches (1998) and Griliches and Lichtenberg (1984) examined the link between research and development (R&D) spending and private-sector productivity in a production-function framework. While the econometrics of adding R&D spending to production functions may seem far removed from the labor market, the analysis can be viewed as an investigation of the demand side of the science and engineering market. About three-quarters of R&D spending consists of wages and salaries of scientists and engineers, and the derivative of the production function with respect to the number of scientists and engineers is the derived demand for those workers.

In the late 1990s and early in the twenty-first century, NBER studies of science and engineering examined the inconsistency between wage, employment, and enrollments data and what seemed like perpetual claims of shortages. Eric Weinstein (2003) analyzed the misuse of evidence on supply and demand data behind some of the 1980s alarmist cries of shortages from major company leaders and government officials, including the National Science Foundation, for which the agency's head eventually apologized. Teitelbaum (2014) documents the history of shortage claims through the first decade of the twenty-first century. Looking outside the shortage debate, Austen Goolsbee (1998) asked whether government R&D policy largely benefited scientists and engineers by driving up their salaries, while Paul Romer (2000) examined the benefits and costs of government subsidies of R&D.

From the first decade of the twenty-first century to the present, research continued on the productivity effects of R&D (see Hall, Mairesse, and Mohnen [2009], among others), but a different set of issues came to the fore in labor market analysis. On the demand side, Lynn Zucker and Michael Darby (2006) looked at the effects of the location of top scientists and engineers on the formation of high-tech firms. On the supply side, Richard Freeman (2005) examined the globalization of the science and engineering workforce and its potential effects on the future position of the United States in the global economy. With Sloan Foundation support, the NBER set up the Science and Engineering Workforce Project that primarily focused on the doctoral workforce in the academic sector, as reported in Freeman and Goroff (2009). Recognizing the increased importance of immigrants and women in the STEM workforce, Jenny Hunt examined where immigrant engineers fit in the education and earnings distribution of engineers (Hunt 2010) and the factors that lead women to leave engineering and science more quickly than men (Hunt 2013).

U.S. Engineering in a Global Economy follows the NBER tradition of quantitative analysis of the demand and supply sides of the engineering job market in the United States. Many of the chapters use novel data or approaches to examine engineering education, practice, and careers in ways designed to inform science and engineering educational institutions, funding agencies, and policymakers about the challenges of developing and employing engineers in ways that most efficaciously contribute to the innovation driving modern economic growth.

Chapter 1 sets the stage for the rest of the book with a review of the engineering labor force, focusing on the employment, salary, and career trajectories of graduates that obtain engineering degrees and work in the field. Lacking a single comprehensive data source on engineers, this chapter draws on a wide variety of longitudinal career data and establishment-based employment and earnings data. These come from different government surveys of scientists, engineers, and employers, including census survey data on the numbers from overseas, and from education administrative data on the supply of engineers coming from U.S. universities. It disaggregates engineering into major subfields, whose employment differs sufficiently to face different supply and demand conditions.

Chapters 2, 3, and 4 focus on supply issues. In chapter 2, Gilmartin, Antonio, Brunhauser, Chen, and Sheppard use a fifty-item survey administered to over 4,000 students across twenty-one U.S. colleges and universities to examine the educational pathways through which junior and senior engineering students move from school to the labor market. They examine the correlations of their postgraduation plans, their psychological motivations, and the attributes of the programs in which they may major. In chapter 3, Weinberger merges data on degrees in historically black colleges and universities (HBCUs) with labor force data to analyze the geography and timing of the increased supply of minority graduates into STEM fields, giving special attention to how the historically black institutions responded to increased opportunities for blacks in engineering when business reduced discriminatory barriers. Chapter 4 presents Brunhauser, Korte, Barley, and Sheppard's analysis of the experience of engineering students who transitioned from their studies to engineering workplaces. Examining the skills the graduates used at work and where they learned those skills, they provide insight into the strengths and weaknesses of educational programs and on-the-job training that economists usually measure simply as years of work experience.
Chapters 5 and 6 turn to the demand side of the market, using different forms of data to investigate the contribution of engineers to productivity and innovation. In chapter 5 Barth, Davis, Freeman, and Wang combine establishment-level production data with firm-level R&D data and census data on the occupations of workers to estimate the contribution of scientists and engineers working outside of R&D labs on the productivity at their workplace. In chapter 6, Helper and Kuan report the results of a survey of over one thousand firms in the automobile supply chain and results of interviews of dozens of engineers, workers, and managers on the contribution of incremental innovations of small suppliers to the growth of productivity that national statistics measure only in final product data. The two chapters mesh together well, as the Helper and Kuan interviews and surveys provide valuable insight into interpreting the statistical calculations of Barth and colleagues in chapter 5.

The last three chapters deal with the operation of engineering labor markets. The United States and most other advanced countries use some form of occupational licensing to ensure that persons practicing in the field have requisite training and skills. Hur, Kleiner, and Wang give a detailed empirical analysis of occupational licensing in civil, electrical, and industrial engineering and its impacts on earnings and employment in chapter 7. In the tradition of the Freeman cobweb model of the interaction of supply and demand, Lynn, Salzman, and Kuehn show in chapter 8 the response of universities and students to an upswing in demand for petroleum engineers that highlights the large elasticity of the domestic labor supply to sharp increases in wages. Examining the increased use of foreign overseas supply of engineers in the United States, Hira uses data from the U.S. Departments of Labor and Homeland Security in chapter 9 to analyze the differences between firms that use the H-1B program to provide lower-cost temporary labor and those using the program as a bridge toward getting permanent immigration status for employees.

Each of the chapters gives a detailed report of the data used, the methodology applied, and the findings. The range of data used to illuminate the job market is wide, from special surveys of graduate students, programs, and firms to administrative data, government surveys, industry, and engineering association reports, licensing and visas, to news reports of firm attitudes and concerns about visas. There is a smorgasbord of information in the chapters and a wide range of references to work in different areas and from different disciplines. To see the linkages among the different studies and the ways in which findings fit together, we summarize below what we view as the three overarching themes from the book.

Supply, Demand, and Globalization

The supply of engineers to the U.S. labor market is responsive to economic conditions because students and engineering programs pay attention to economic signals and globalization provides new channels of supply.

Three of the chapters give evidence of the supply responsiveness by students and universities that gainsay the view that the U.S. supply system functions poorly and that underlies the perennial warnings about shortages of scientists and engineers. The findings of these chapters provide strong evidence that students and the educational institutions that prepare them for careers in science and engineering are aware of economic opportunities and are quick to respond to these opportunities and market signals.

The strongest evidence of sizable supply responses are given by analyses of the flow of students and by changes in university programs responding to market conditions. Given historically limited opportunities for black graduates in the private sector, relatively few blacks became engineers and historically black colleges provided limited educational offerings in engineering. Weinberger's analysis shows that when the barriers of discrimination lowered, businesses, foundations, and HBCUs made a concerted effort to expand educational opportunities in engineering, computer science, and other technical fields, "to prepare their students for expanded career choices." Students responded and the result was a substantial increase in the number of college-educated black men and women entering engineering, particularly from the six HBCUs that were in the forefront working with businesses and foundations. Treating the opening of new programs as a supply-side shock to educational opportunity, Weinberger finds that the graduates who went into these STEM fields had better labor market outcomes than those in other occupations or in earlier birth cohorts.

The Lynn, Salzman, and Kuehn study documents the responses to a quasi-natural experiment in petroleum engineering when, early in the twenty-first century, demand for that specialty increased greatly after decades of little hiring. Industry raised entry-level wages, and within two to three years the number of graduates in petroleum engineering began increasing so rapidly that by 2015 the number of graduates was five times the number in 2005-2006! Even in a very specialized field, supply is highly responsive to traditional market signals of wages. Interviews with department chairs and others show the effort by academic institutions to increase supply so as to meet the market demand.

The Gilmartin, Antonio, Brunhaver, Chen, and Sheppard analysis of students who major in engineering gives a more nuanced picture of supply behavior. It finds that "over two-thirds [of engineering students] having non-engineering, mixed, or uncertain plans," and these students differ from the students with engineering-focused career plans based on modest differences in median salaries in their region. It is notable that engineers show greater
flexibility for their future work plans than one might have expected from such specialized education, “with over two-thirds having nonengineering, mixed, or uncertain plans.” The openness that students show to pursue pathways outside of engineering is consistent with evidence that about one-third of the 70,000–75,000 engineering graduates in the United States each year take nonengineering jobs because they report finding other careers more attractive (Salzman, Kuehn, and Lowell 2013).

Productivity and Innovation

Engineers and scientists outside of formal R&D raise productivity both in their company and through innovations along the supply chain to places beyond their employer.

Three chapters use different types of data to give evidence on the link between what scientists and engineers do outside of formal R&D activities and productivity. It is important to analyze what these non-R&D scientists and engineers do because they make up the majority of persons in science and engineering occupations. Between 70 and 80 percent of scientists and engineers in U.S. industry work on non-R&D activities. At the doctoral level, 45 percent of all Ph.Ds in the industry report that their work does not include research as a primary or secondary activity. Traditional production-function analyses that make R&D the key determinant of labor or total factor productivity neglect the possibility that the contribution of these scientists and engineers makes to output by implementing or improving new technologies and the impact of such improvements along the supply chain to other firms.

Barth, Davis, Freeman, and Wang’s production-function investigation shows that in manufacturing, establishments that have higher proportions of scientists and engineers have higher productivity in both cross-section comparisons of establishments and, perhaps more convincingly, in comparisons of the same establishment when it changes the proportion of its workforce in science and engineering over time. The evidence further suggests that the effects of having more scientists and engineers at establishments is larger, the greater the intensity of R&D activity. Some of the benefits from higher productivity appear, moreover, to spill over to higher earnings for non-STEM workers.

The Helper and Kuan surveys and interviews show that many non-R&D engineers contribute to the introduction of new products or processes and/or to lowering costs of production, providing examples of both effects. They find that engineers at supplier firms in the automobile sector contribute many incremental gains that would not meet the term “innovation” nor fit under any R&D rubric, and that many work closely with customers in generating improvements. Further, some non-R&D engineers work closely with production workers and thus jointly contribute to productivity improvements. Their findings support the notion that standard production functions that focus solely on the R&D pathway to technological progress do not capture the reality of how non-R&D engineers contribute to productivity. This analysis also shows wide heterogeneity in firm policies and practices, even within the same detailed industry classification.

Finally, Brunhaver, Korte, Barley, and Sheppard’s interviews with early career engineers about their actual work gives further insight into what engineers do outside formal R&D facilities. These engineers report their work as more variable and complex than academic curricula convey. Moreover, their work often “is less about using theories or equations, for example, than about project management and working with other people.” While these interviews did not probe into low (if at all) their work raised productivity, it shows the importance of nontechnical skills even for beginning engineers in industry. Parenthetically, it also fits with the openness that engineering students have toward alternative career paths and curriculum reforms that broaden the scope of skills that make up an engineering degree, and with other studies of employers saying the nonengineering skills are those that are the harder to find and the more sought after skills of new graduates (Lynn and Salzman 2010).

The findings in these three chapters from different data, enterprises, and industries provide breadth in examining aspirations and plans of young engineers, the productivity outcomes from the work of incumbent scientists and engineers, and how engineers outside of R&D improve efficiency at their own firm and across different points in the supply chain. They show consistency in the conclusion that engineers contribute to productivity and innovation much more broadly than recognized in formal models of R&D activity.

Education and Labor Markets

There is considerable variation in the way the institutional structure of education and labor markets affects outcomes.

Market outcomes depend not only on the classic forces of supply and demand but also on the institutional or legal structure that influence the decisions or that determine outcomes through law or regulation. Two chapters of the book examine how laws and regulations affect the engineering job market.

Hur, Kleiner, and Wang’s analysis of the licensing of engineers shows that it has expanded over time with, however, large variation in its existence and strictness across states that, surprisingly, is unrelated to the usual state policies regarding labor regulations. States with the most restrictive licenses included Georgia, Texas, Pennsylvania, and Illinois, while the states with the least restrictive licensing laws were Virginia and Minnesota. But regulations had small and often insignificant impacts on wages or hours worked, implying that market forces dominated the nature of licensing. While not the
main focus of Lynn, Salzman, and Kuehn's analysis of petroleum engineering, they also found that market forces in higher education overwhelmed the efforts by two leading petroleum engineering departments, Texas A&M and University of Texas at Austin, to moderate student supply responses in the hope of avoiding an excessive increase in supply when wages increased for petroleum engineers. However, the dramatic increase in wages induced enough other departments to admit students to create the fivefold increase noted earlier, resulting in graduating more engineers than industry was hiring, and coincided with a decline in oil prices that further depressed demand. Taken together, these two studies show that broad market forces are sufficiently strong to overwhelm the effects of states acting individually through licensure and of large departments acting individually in their admission policies to have any noticeable effect on outcomes.

Hira's analysis of H-1B visas tells a more complex story about the interaction between institutions and market forces. On the one side, the H-1B law determines the number of visas for temporary migrants and thus bounds the supply of such workers. By lodging control of the visas with the employer, the H-1B program further segregates H-1B migrants from the general labor market for engineers. The H-1B recipients cannot change employers and use the normal channel of job changes or threats of changes to improve their economic position, which assures that employers are major beneficiaries of the program. On the other side, the market forces and company strategies in different parts of the IT industry lead firms to use the visas in different ways within the same institutional framework. One set of employers uses the H-1B program solely for getting work done at low wages, hiring foreign workers with no effort to sponsor them for permanent residency. Another set of employers pays higher wages to their H-1B workers and appears to use the H-1B program as a way of selecting some workers to integrate into their permanent workforce by sponsoring them for permanent residency.

In sum, the book offers insight into a variety of issues in the changing market for engineers and highlights others that might be fruitfully addressed in future research. We need to know more about the actual work activity of persons with engineering and other STEM degrees not only outside R&D, which the book deals with, but outside science or engineering entirely to get a full picture of the value of this formal education, and of ways to improve the link from schooling to work. We also need to better understand the ways in which firms, students, and training institutions respond to a global market in which U.S. workers and firms face competition unlike that which we have had in the past. In addition, we need insight into the best ways to improve science and engineering education to fit current and future demands of the workforce and, as always in economics, about the wide heterogeneity of labor market outcomes among workers and firms and their relation to explicit policies and regulations.

References


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.

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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.

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. 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.

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.

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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. 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 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 fracturing 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). 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 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 have already 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 83 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 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. 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
large differences in the two surveys mentioned above are for earlier years). 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 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.
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...
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). As oil prices sharply declined in 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; Lasseter 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 spokespersons (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


Bridge to Permanent Immigration or Temporary Labor? The H-1B Visa Program Is a Source of Both

Ron Hira

9.1 Introduction

Many members of the popular press, pundits, business and university leaders, and policymakers conflate and often confuse guest worker visas, such as the H-1B, with permanent immigration. Carly Fiorina, an advisor to John McCain’s presidential campaign in 2008 and former chief executive officer (CEO) of Hewlett-Packard, responded to a question about H-1Bs during the campaign this way, “It is in our economic interest to have really smart people wanting to come here. And so what’s wrong with the H-1B visa system today, among other things, is that we curtail that program so tightly that the limits that Congress allows for H-1B visa entrance are usually filled within one week. So we have to find a more practical system for allowing smart, hardworking people to come into this country and it should be our goal to get them to stay here forever” (Bomey 2008). Reading the quote, one might expect that expanding the H-1B program is the critical change to immigration policy that is needed in order to keep skilled workers here permanently. While permanent residence allows foreign nationals to live and work in the United States permanently, guest worker visas like an H-1B allow them to live and work in the United States only temporarily (not “forever”) and under circumstances that restrict their ability to stay in the coun-

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1. Some justify expansion of the H-1B program on the grounds that immigrants found new companies in the United States (Friedman 2009; Washington Post 2008). However, by regulations H-1Bs are not allowed to found a company.