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Introduction

Richard B. Freeman and Hal Salzman

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 Sput-

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nik was 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, Brunhaver, Chen, and Sheppard use a fifty-item survey instrument 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 the 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 Brunhaver, 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 PhDs 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 possible contribution these scientists and engineers make 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 how (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.

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