Engineering in a Global Economy

Introduction

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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 USSR—to the present, the state of the labor market for specialists in STEM (science, technology, engineering, mathematical) occupations has been a major and controversial topic in economics, labor relations, and public policy. The National Bureau of Economic Research (NBER) has a long history analyzing the science and engineering workforce, beginning with Blank and Stigler's *The Demand and Supply of Scientific Personnel* (1957), which came in the same year that Sputnik's launch raised concerns about the United States losing technological leadership due to shortages of scientists and engineers. 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 the industry were, at that time, engineers. Today, engineers remain more numerous then scientists in business but the expansion of the bio-medical workforce and the huge number of computer science and other IT workers has eroded the numeric dominance of engineering among STEM workers in total.

The central issue in the labor market analysis of engineers following Sputnik was the meaning of a shortage in a flexible market where wages cleared supply and demand.

When demand goes up 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 US effort to surpass the USSR in space technology. Freeman (1971) put the supply and demand responses together into a cobweb model in which the lag between the change in wages due to demand shocks, and ensuing supply responses due to the years of education learning STEM skills, induced cyclical fluctuations in wages and employment. Engineering was the prime exemplar of this pattern.

In the 1980s and 1990s NBER work by Zvi Griliches (1984,1998) examined the link between research and development (R&D) spending and private sector productivity in a production-function framework. While the econometrics of production functions may seem far removed from the labor market per se, 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, the majority of whom are 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 2000s, NBER studies of science and engineering gave renewed focus to labor market issues, taking a critical view of what seemed like perpetual claims of shortages. Eric Weinstein's (1998) “How and Why Government, Universities, and Industry Create Domestic Labor Shortages of Scientists and High-Tech Workers” analyzed the misuse of evidence on supply and demand data behind some of the 1980s alarmist cries of shortages coming from major company leaders and government officials, including the National Science Foundation, for which the agency's head eventually apologized (Teitelbaum, 2014, has recently examined the history of shortage claims through the 2000s). 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.

In the 2000s to the present, research continued on the productivity effects of R&D (see Bronwyn Hall 2009, among others), but a different set of issues came to the fore. 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 doctorate 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 (2010) and the factors that lead women to leave engineering and science more quickly than men (2013).

Engineering in a Global Economy follows the NBER tradition of quantitative analysis of both the demand and supply sides of the engineering job market, while also expanding the scope beyond the United States to consider the practice of engineering and innovation in a global economy. It uses novel data to examine engineering education, practice, and careers in ways that will hopefully inform science and engineering educational institutions, funding agencies, and policymakers about the challenges of developing an engineering workforce that contributes substantially to the innovation that drives modern economic growth; and that not only highlights what we have learned but the issues which require further analysis.

Chapter one sets the stage for ensuing studies with a review of the engineering labor force, from numbers of graduates to enter into the field and exit from it to other occupations over the life cycle. It analyzes employment, salary, and career trajectories using data sets that range from education administrative data to census surveys in ways that are mindful of the Blank and Stigler book (1957) that was NBER's first major foray into the market for scientists and engineers. 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 available from different government surveys of scientists and engineers and employers.

Chapters two, three, and four focus on supply issues. In chapter two, Gilmartin et al. use a 50-item survey instrument administered to over 4,000 students across 21 US 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 post-graduation plans, including measures of their psychological motivations and attributes of the programs in which they may major. In chapter three, Weinberger merges data on degrees in historically black colleges and universities 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 the rapid response of the historically black institutions to increased opportunities for graduates in engineering.

Brunhaver, et al. analyze data on a group of engineering students who transitioned from their studies to engineering workplaces in chapter four. 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 five and six turn to the demand side of the market, using different forms of data to investigate the contribution of engineers to productivity and innovation. In the tradition of the Griliches production function analysis, Barth et al. combine establishment-level production data with firm-level R&D data and census data on occupations to estimate the contribution to productivity at their firm by scientists and engineers working outside of R&D labs in chapter five. In chapter six, Helper and Kuan surveyed thousands of firms in the automobile supply chain and interviewed dozens of engineers, workers, and managers to assess the ways in which the innovations of small suppliers contributed to the growth of productivity that national statistics measure only in final product data.

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 seven. In the tradition of the Freeman cobweb model of the interaction of supply and demand, Lynn, Salzman, and Kuehn show the responsiveness of universities and students to market opportunities during an upswing in demand for petroleum engineers in chapter eight. They highlight the responsiveness of the domestic labor supply to sharp increases in wages. Examining the increased importance of foreign-born engineers to the supply in the United States, in chapter nine Hira uses data from the US Departments of Labor and Homeland Security to analyze the differences between firms which use the H1-B program to provide lower-cost temporary labor and those using temporary visas 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. As the introduction above indicates, the chapters use a wide-ranging set of data, from special surveys of graduate students, programs, and firms to administrative data, government surveys, industry and engineering association reports, and evidence on licensing and 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 on key issues in engineering education, careers, and the role of engineering in the economy. To see the linkages between the different studies and the ways in which findings fit together, we summarize below what we view as the three overarching themes that emerged from a conference that brought together researchers, policymakers, and managers and executives from industry, and the research that resulted from the conference and became the subject of the chapters of this book.

1. The supply of engineers to the US labor market in the 2000s is responsive to economic conditions because students and engineering programs pay attention to economic signals and because globalization provides new channels of supply.

Four of the chapters give evidence of the supply responsiveness by students and universities that gainsay the view that seems to underlie the perennial warnings about shortages of scientists and engineers, namely that students and the educational institutions that prepare them for careers in science and engineering are either unaware of economic opportunities or too slow to respond.

The strongest evidence of sizable supply responses are given by analyses of the flow of students or by university programs responding to market conditions. Weinberger's analysis of the increased flow of minority students into engineering and computer science begins with the remarkable fact that through the 1960s, about half of black engineers in the United States were trained in one of six historically black colleges and universities (HBCUs) and that most other HBCUs did not offer substantive training in STEM fields. Given historically limited opportunities for black graduates in the private sector, there seemed little need for increased training. As 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 from the south entering engineering or computer science occupations. 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 in chapter eight documents the responses to “a quasi-natural experiment” in the case of petroleum engineers when, in the early 2000s, demand for that specialty increased greatly after decades of little hiring and industry raised entry-level wages. Within two to three years the number of graduates in petroleum engineering began increasing so that by 2012 the number of graduates grew fivefold over the number in 2005-06! Even in a very specialized field, supply is highly responsive to traditional market signals of wages. Interviews with department chairs and others show the extent to which academic institutions sought to increase supply to meet the market demand.

Hira's analysis of firms’ use of H1-B visas shows a different form of supply response, where the supply of workers is highly elastic (due to better opportunities and higher pay in the United States than in most other countries), but it is a program where employers and federal government regulations determine how many temporary workers firms can recruit. Firms obtaining the largest share of temporary worker visas, which includes most of the top users of the program, appear to use the program as a way of getting less expensive labor into the United States in what might be called on-shore offshoring. But other firms help their H1-B workers obtain permanent residency. By design, this temporary visa program produces a labor force more controlled by employers than labor law allows for domestic workers and creates a bifurcated supply, of lower-paid temporary workers largely engaged in firms providing offshored IT services and another group in IT product firms who are higher paid and more likely to be sponsored by their employer for permanent visa status.

The Gilmartin, et al., analysis of students who major in engineering gives a more nuanced picture of supply behavior among those who have chosen this field. While it finds that “ the median salary of professionals in the same field and in the same state in which their college or university is located modestly differentiates students who have engineering-focused post graduation plans from students who have non-engineering focused plans,” arguably the most striking result is the flexibility that so many engineering students have for their future work: “with over two-thirds having non-engineering, mixed, or uncertain plans.” They note that computer science/engineering majors have the highest rate of intention to pursue engineering graduate school, which may reflect the high salaries for such training. The openness that students show to pursue pathways outside of engineering is consistent with evidence that about one-third of the United States’ 70-75,000 engineering graduates each year take non-engineering jobs because they report finding other careers more attractive (Salzman et al., 2013).

2. Engineers and scientists outside of formal R&D activities raise productivity where they work, and indirectly through innovations along the supply chain to places beyond where they work; they also gain considerable skills through on-the-job training.

Between 70 and 80 percent of scientists and engineers in US industry work on non-R&D activities. At the doctorate 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, essentially ignore the possible contribution of these scientists and engineers to output by implementing or improving new technologies. Traditional production-function analyses that use firm or establishment value added as the output measure ignore the possible contribution of scientific-engineering innovations at firms that produce intermediate goods or machinery and capital for final end products to productivity.

In chapter five Barth et al. show that in manufacturing, establishments which 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 among companies that engage in R&D, the effects of having more scientists and engineers at establishments is larger, the greater the intensity of R&D activity. As a check on the production function analysis, Barth et al. also examine the relation between the wages of workers in an establishment and the S&E proportion of workers in an establishment, conditional on other factors, and find that working in an establishment with a higher proportion of S&E workers is associated with higher earnings for all workers.

In their investigation of what engineers and scientists do outside formal R&D, Helper and Kuan use a nation-wide survey and dozens of interviews at firms in the supply chain of the automobile industry, which has long been the single largest employer of engineers in the United States and an extensive user of the supply chain mode of production in chapter six. They find that engineers at supplier firms contribute many incremental gains that would not meet the term "innovation" to the main product but that cumulate to a steady improvement in price, performance, or both.

The Brunhaver et al. longitudinal survey and in-depth interviews of working engineers in four companies in chapter three provides a unique picture of what engineers outside formal R&D facilities do at their work, and their use of on-the-job skills relative to those learned in college. They find that engineering work is more variable *and* complex than most engineering curricula convey, noting in particular that "a young engineer's work is less about using theories or equations, for example, than about project management and working with other people." The implications for engineering education and employer engagement and training fit with the openness that engineering students have toward alternative career paths: to widen the scope of skills to focus on thinking like an engineer rather than getting an engineering degree. Combining survey questions and interviews about the specific tasks and skills used on the job with studies of productivity of workplaces as in Barth et al. or Helper and Kuan would greatly illuminate the contribution of engineers and other STEM workers in productivity and innovation, as well as providing additional evidence about college engineering curriculum. But we did not make the connection between the qualitative survey of skills and establishment productivity and innovation until after the research was done.

Taken together, these studies suggest that standard analyses underestimate the contribution of the work of scientists and engineers to bottom-line productivity be it through the spread of R&D-created knowledge within firms or incremental improvements within and across firms.

3. Market Rules and Links

The supply of engineers depends not only on the decisions of persons and firms but also on the way decisions interact in a market setting and on the rules or regulations that influence the decisions or the outcomes of the decisions. In chapter six, Hur, Kleiner and Wang examine the role of licensing of engineers on market outcomes. They report that licensing became more rigorous beginning in this century but there is still a large variation across states, which allows them to estimate the effect of the strictness of the laws on wages and hours worked, both of which are higher in the presence of stricter laws. The range of variation in the licensing indexes, from education to experience to exams, shows that states had a menu of possible ways to regulate engineering. But their finding that the most restrictive states included Georgia and Texas along with Pennsylvania and Illinois, and that the least restrictive were Virginia and Minnesota, highlights their conclusion that the forces that produce regulations for labor broadly were not operating for engineering licenses.

Lynn, Salzman, Kuehn's evidence that, in petroleum engineering at least, supply responses were sufficiently elastic, raises the potential of market problems in the future: their findings also draw attention to fears that indeed the end result would be a job market collapse for graduates, as has occurred for different engineering specialties in the past. They note two of the largest petroleum engineering departments, Texas A&M and University of Texas at Austin, controlled their expansion for this reason, however with little impact on the market as other universities chose to expand in response to student enrollments. The United States does not have the institutional structure for universities to limit student choices and thus increasing supply beyond demand is a likely short-term outcome when there is a sharp increase in wages.

Hira's analysis of the H-1B visa, discussed earlier as a factor in the supply of STEM workers, shows substantial differences in the way firms use the short-term work visa that depends on the nature of the firms and the economic conditions facing them. Product firms sponsor guest workers for permanent residency at much higher rates than offshoring IT services firms, suggesting that technology workers at product firms are able to use these temporary visa programs as a bridge to permanent immigration. Offshoring firms, however, have very low rates of sponsorship for permanent residency and provide lower wages, have a flatter wage distribution, and hire workers with lower education than those working as guest workers at product companies. The data suggest that the guest worker visa program is being used quite differently by firms in different industry segments and inconsistent with the intent of the visa program objectives.

In sum, the book offers insight into a variety of issues in the changing market for engineers and highlights others that might fruitfully be addressed in future research. In particular, we need to know more about the actual work activity of persons with engineering and other STEM degrees working in non-science or engineering jobs to get a full picture of the value of this formal education, and of ways to improve the link from schooling to work. In particular, we need to better understand the ways for firms, students, and training institutions to respond to a global market in which US workers and firms face competition unlike that which we have had in the past when the United States was by far the dominant country in graduating scientists and engineers and on the forefront of technology in most sectors.

References

Arrow, Kenneth, and William Capron. 1959. "Dynamic Shortages and Price Rises: The Engineer-Scientist Case." *The Quarterly Journal of Economics* 73(2): 292-308.

Blank, David, and George Stigler. 1957. *The Demand and Supply of Scientific Personnel*. Cambridge, MA: National Bureau of Economic Research.

Freeman, Richard. 1971. *The Market for College-Trained Manpower*. Cambridge, MA: Harvard University Press.

Freeman, Richard. 2005. "Does Globalization of the Scientific/Engineering Workforce Threaten U.S. Economic Leadership?" National Bureau of Economic Research, Working Paper 11457.

Freeman, Richard, and Daniel Goroff. 2009. *Science and Engineering Careers in the United States: An Analysis of Markets and Employment* (National Bureau of Economic Research Conference Report). Chicago: The University of Chicago Press.

Griliches, Zvi and Frank Lichtenberg. 1984. "Interindustry Technology Flows and Productivity: A Reexamination." *The Review of Economics and Statistics* 22(2): 324-329.

Griliches, Zvi. 1998. *R&D and Productivity: The Econometric Evidence* (National Bureau of

Economic Research Monograph). Chicago: The University of Chicago Press.

Hall, Bronwyn, Jacques Mairesse, and Pierre Mohnen. 2009. "Measuring the Returns to R&D." National Bureau of Economic Research, Working Paper 15622.

Goolsbee, Austen. 1998. "Does Government R&D Policy Mainly Benefit Scientists and Engineers?" National Bureau of Economic Research, Working Paper 6532.

Hunt, Jennifer. 2010. "Why Do Women Leave Science and Engineering?" National Bureau of Economic Research, Working Paper 15853.

Hunt, Jennifer. 2013. "Are Immigrants the Best and Brightest U.S. Engineers?" National Bureau of Economic Research, Working Paper 18696.

Romer, Paul. 2000. "Should the Government Subsidize Supply or Demand in the Market for Scientists and Engineers?" National Bureau of Economic Research, Working Paper 7723.

Salzman, Hal, Daniel Kuehn, and B. Lindsay Lowell. 2013. "Guestworkers in the High-Skill U.S. Labor Market: An Analysis of Supply, Employment, and Wage Trends (Briefing Paper #359)." Washington, DC: Economic Policy Institute.

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

Weinstein, Eric. Undated working draft. "How and Why Government, Universities, and Industry Create Domestic Labor Shortages of Scientists and High-Tech Workers." National Bureau of Economic Research: http://users.nber.org/~peat/PapersFolder/Papers/SG/NSF.html.

Zucker, Lynn, and Michael Darby. 2006. "Movement of Star Scientists and Engineers and High-Tech Firm Entry." National Bureau of Economic Research, Working Paper 12172.