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1 The Engineering Labor Market
An Overview of Recent Trends

Daniel Kuehn and Hal Salzman

1.1 Introduction

The role of engineers in developing infrastructure, technology, and innovation has long made the economic health of the profession an issue of concern for public policy. In the Great Depression, engineers were critical in developing the New Deal public infrastructure that boosted employment. In World War II, engineers were critical in advancing military technology and deploying it in the field, which raised national security concerns about bottlenecks due to limited supply (Allen and Thomas 1939). After the war, many saw engineers and scientists as vital to national security and economic prosperity. In 1945, Vannevar Bush (an engineer himself) articulated the need for a strong science and engineering workforce in his famous statement on the "Endless Frontier" of scientific and technological progress (Bush 1945). For most of the next several decades, policymakers worried about shortages of engineers and scientists.[1] Shortage fears reached a crescendo in 1957, when the Soviet Union's launch of Sputnik seemed to threaten U.S.

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1. An exception was the late 1940s when there was a brief concern about engineering surpluses.

technological preeminence. But economists found little evidence of a classic market "shortage" in labor market data on wages, employment, and graduates (Arrow and Capron 1959; Blank and Stigler 1957; Hansen 1967). Ensuing work recognized that the labor market for engineers functions differently from labor markets where demand and supply clear markets quickly because engineering education requires intensive and highly prescribed curriculum, causing supply to lag demand, and that because firms cannot easily find substitutes for engineering skills, wages may be driven up considerably in the short term, producing resultant cobweb-type cycles not found in most labor markets (Freeman 1975, 1976; Ryoo and Rosen 2004).

Still, labor shortage fears have persisted into the twenty-first century (Teitelbaum 2014), perhaps most notably in the National Academy of Science and National Research Council's report, *Rising above the Gathering Storm*. Invoking Churchill's characterization of Germany's threat to Europe in his book, *The Gathering Storm*, the report was written to raise an alarm about the growing threat to the United States by the rise of other nations' science and technology capabilities and insufficient U.S. investment in its own research and development (R&D). Warning that "The nation must prepare with great urgency to preserve its strategic and economic security" (National Academy of Science et al. 2007, 4), the report recommended increasing the number of engineering graduates to keep up with the large numbers graduating in countries such as China. As with the earlier post–World War II cries of shortage and calls for more engineers, these recommendations lacked clear and convincing evidence of unmet domestic demand.[2]

This chapter provides background information on the engineering workforce and trends in the supply of new engineers to the labor market that set the stage for the rest of the book.

The chapter begins with an overview of the engineering workforce and the changes in its detailed occupational composition and distribution across industries over time. Since demand is thought to generally lead supply in this market, we then review the factors influencing the demand for engineers. This includes changes in the demand for engineers across industries, fluctuations in government demand, and replacement demand. This discussion provides context for interpreting trends in the supply of new engineers with undergraduate degrees and graduate degrees from American colleges and universities, which are presented in section 1.3.

The data in the demand section come from the decennial census, the American Community Survey (ACS), the Bureau of Labor Statistics' Occupational Employment Statistics (OES), and the National Science Foundation's (NSF) semiregular Scientists and Engineers Statistical Data System

2. While *Gathering Storm* gained the most attention, other reports endorsed the call for more engineers and scientists, most prominently the President's Council on Jobs and Competitiveness ([2011], 33–34; see Salzman [2013], Lynn and Salzman [2010], Lowell and Salzman [2007], and Teitelbaum [2014] for reviews of *Rising above the Gathering Storm* and related reports).

(SESTAT) that combines information from three NSF surveys, the National Survey of College Graduates, the National Survey of Recent College Graduates, and Survey of Doctoral Recipients (SDR) to construct a nationally representative sample of college-degree holders. The chapter focuses on the subset of degree holders in the SESTAT data who earned at least one degree in an engineering field, but it uses ACS and OES data rather than SESTAT for time-series analysis due to changes in the SESTAT sampling frame.[3] The data in the supply section comes from the Integrated Postsecondary Education Data System (IPEDS), which collects detailed annual enrollment and graduation information from the approximately 6,700 postsecondary institutions that accept federal financial aid.

While there is value in analyzing all persons with engineering degrees regardless of where they work, or all persons who report working in an engineering occupation regardless of their education, many of these analyses using the SESTAT and ACS are restricted to persons working as engineers with engineering degrees. These restrictions make the SESTAT analyses more comparable to the IPEDS data. This leaves out engineering graduates who work in other occupations[4] and persons who say they work in an engineering occupation but do not have a bachelor's degree in engineering.[5] The OES data cannot be restricted by field of degree.

1.2 The Engineering Workforce: Demand and Salaries

An engineer is defined by the Bureau of Labor Statistics—across the various subfields—as a worker who designs, develops, and tests solutions to technical and physical problems faced by industry and government. Although popular analyses and policymakers typically refer to engineers as a single group, with the assumption that this represents a more or less homogeneous workforce and labor market, it is instead a remarkably heterogeneous workforce in terms of education, skills, industry representation, and work performed. Civil engineers, for example, are primarily involved in construction work and employed in independent engineering firms and government ("public administration" is the title used in standard industrial classification statistics). In contrast, aerospace engineers are seldom self-

3. In 2010, the SESTAT was drawn from a new sampling frame, the ACS. Prior to 2010 the sampling frame of the SESTAT was the decennial census. Wage and salary data, particularly for engineering graduates working as managers, revealed considerable instability between 2008 and 2010, suggesting that the 2010 and 2013 SESTAT should be interpreted with caution in the context of any time-series comparison with prior years of that survey.

4. In 2013, for example, only 38 percent of all engineering bachelor's degree holders reported they worked as engineers.

5. Between one-fifth and one-quarter of all persons who report working as engineers have college degrees outside engineering and nearly 12 percent have no postsecondary degree at all, presumably obtaining their skills through on-the-job training or working in a highly firm-specific task.

employed or employed by engineering firms, working instead for large aerospace manufacturing firms. Since aerospace engineers are reliant on large military and civilian aviation industry contracts, they are less affected by normal business cycle dynamics than civil engineers whose work is directly affected by levels of construction activity. Mechanical engineers are affected by the business cycle, but their employment levels are sensitive to the decisions of individual firms about the global location of manufacturing operations in a way that might not affect civil engineers.

Although engineering work is a crucial component, if not driver, of much technology innovation, a small portion of the overall engineering workforce is working directly on new technologies or in new product industries. NSF estimates that two-thirds of engineers report research or development as either a primary or secondary work activity (National Science Board 2014, table 3-10), but interpreting the meaning of this statistic for engineering is somewhat different from other occupations. In engineering, a civil engineer might, for example, consider each building project "development" work and it is, in fact, new development in the sense that each new construction project is different from past projects and may require new engineering solutions and innovation. However, this is not what is generally regarded as the type of innovation of interest to policymakers. Most engineers are not creating new technology or developing new products or industrial processes; they are busy designing bridges, roads, power plants, factories, and buildings, and running manufacturing operations. Alternatively, using the industry segment to identify "innovation" work indicates just under 5 percent of engineers (or just over 75,000) are in "scientific research and development services," though many more are involved in key innovation activities in other industries and thus this statistic greatly understates the role of engineers in innovation. Engineering is clearly important to innovation, but most engineers are engaged in "development" rather than the "research" types of R&D that are generally regarded as the innovation of new products. At the same time, the role of engineering outside of formal R&D occupations or work is still vitally important to the use of new products and improvements in production processes, a vital component of commercialization of innovation (see Helper and Kuan, chapter 6, this volume; Barth, Davis, Freeman, and Wang, chapter 5, this volume). Thus, when discussing the role of engineers in innovation it is important to specify the particular subfields, occupational roles, and types of innovation that are of interest rather than refer to the entire engineering fields of work or occupations.

The employment patterns of engineers vary according to the specific field and industry of employment as different segments of the American economy, such as construction or manufacturing change. Table 1.1 presents selected shares of engineering occupations employed in major industry categories in 1980 and 2010 for each detailed engineering occupation. Some occupations, like computer engineering and environmental engineering,

Table 1.1 Engineering employment in industry: Percentage of top three industries (1980 or 2010) for each engineering occupational subfield

Occupation	Largest industry (1980 or 2010)	1980	2010	Second-largest industry	1980	2010	Third-largest industry	1980	2010
Aerospace	Manufacturing	88	86	Professional, scientific, and technical services	4.1	7	Public administration	5	3.8
Biomedical & agricultural	Manufacturing	53	54	Education, health, arts, entertainment, and other services	24	29	Public administration	14	3.3
Chemical	Manufacturing	81	90	Professional, scientific, and technical services	9	6			
Civil	Construction	40	24	Professional, scientific, and technical services	24	60	Public administration	16	8
Computer	Professional, scientific, and technical services	—	37	Manufacturing	—	32	Finance, insurance, and real estate	—	9
Electrical	Manufacturing	50	45	Professional, scientific, and technical services	11	21	Information technology	16	11
Environmental	Professional, scientific, and technical services	—	43	Public administration	—	19	Transportation and utilities	—	15
Industrial	Industrial	80	76	Professional, scientific, and technical services	3.5	12			
Marine	Transportation and utilities	58	20	Manufacturing	21	48	Professional, scientific, and technical services	9	15
Materials	Manufacturing	78	90	Professional, scientific, and technical services	7	5			
Mechanical	Manufacturing	76	73	Professional, scientific, and technical Services	10	14			
Mining & petroleum	Mining and extraction	80	72	Manufacturing	6	10	Professional, scientific, and technical services	5	8
All other engineers	Manufacturing	37	31	Professional, scientific, and technical services	35	36	Public administration	12	15
Engineering technicians	Manufacturing	47	42	Professional, scientific, and technical Services	12	13	Education, health, arts, entertainment, and other services	10	10

were not recorded as separate fields in 1980. Presumably the small number of engineers doing comparable work in 1980 was categorized as electrical engineers (computer) or civil engineers (environmental).

Engineers are concentrated in the manufacturing sector, with half working in that industry in 1980, declining to 44 percent in 2010. Several engineering fields are heavily concentrated in manufacturing such as aerospace, chemical, industrial, marine,[6] and materials engineers, in addition to engineering technicians. Biomedical and agricultural engineers also have been employed primarily in manufacturing, although roughly one-quarter of this field is also employed in the health sector, with the health-sector employment presumably made up primarily of biomedical engineers. The manufacturing sector shed well over one-quarter of its total workforce between 1980 and 2010, mostly from 2000 to 2010, due to a combination of productivity improvements, offshoring, and loss of market share to foreign competition (Congressional Budget Office 2008). Despite this substantial decline in the total manufacturing workforce, the number of engineers employed in manufacturing was virtually identical in 1980 and 2010 (1,071,700 in 1980 compared to 1,077,400 in 2010). Over the same period, manufacturing production increased by almost 80 percent with a smaller total workforce and a stable number of engineers employed.[7]

The share of engineers in the professional, scientific, and technical services (PSTS) industry grew from 14 percent to 25 percent over the past thirty years. In absolute terms, the number of engineers in this sector more than doubled from 301,800 in 1980 to 614,700 in 2010. The PSTS industry is composed of engineering consulting firms, so their growth is likely due to the outsourcing of engineering tasks from in-house engineering to consulting engineering firms (Yuskavage, Strassner, and Medeiros 2009). The largest shifts of engineering occupations into the PSTS industry have been civil and electrical engineers, also two of the largest engineering occupations, comprising almost 18 percent and over 13 percent, respectively, of all engineers.[8] Electrical engineering concentration in the manufacturing sector fell between 1980 and 2010, while civil engineering concentration declined in the construction and "public administration" (government) sectors, from 40 percent to 24 percent, and 16 percent to 8 percent, respectively; civil engineers in PSTS grew from 24 percent to 70 percent of all civil engineering employment. This

6. Caution should be used in interpreting percentage changes in occupations with small workforces such as marine engineering (in 2010 there were 11,000 marine engineers in the United States). Small sample sizes, the change from using the census long form to the ACS sample, and changes in the industry and occupational classifications could account for instability in the population estimates.

7. Authors' calculations from the Federal Reserve Board's G.17 Industrial Production and Capacity Utilization tables (Board of Governors of the Federal Reserve System 2011).

8. Authors' calculations from the 2010 census. The single largest engineering occupational group, a miscellaneous engineering category, comprises almost a quarter of all engineers.

Table 1.2 Industrial sectors employing engineers

Sector	Number	Percent
Agriculture and forestry	1,931	0.1
Mining	34,064	1.8
Construction	96,321	4.9
Manufacturing	868,505	45
Wholesale	15,828	0.8
Retail	13,215	0.7
Transportation and warehousing	26,158	1.3
Utilities	81,769	4.2
Information	57,830	3.0
Finance, insurance, and real estate	16,559	0.9
Prof., sci., and tech. services	548,406	28
Educational and health services	36,332	1.9
Arts and entertainment	5,236	0.3
Other services	7,718	0.4
Public administration	140,448	7
Total	1,950,320	100

Source: Authors' calculations from the 2010 ACS.

sector shift out of manufacturing, construction, and public administration may overstate the shift in engineering activity—of independent engineering firms in the PSTS sector, many may still be providing engineering services to a similar profile of client industries (e.g., construction, manufacturing). The PSTS industrial sector includes architectural services as an industrial subsector, which is particularly important in accounting for the growth in employment of civil engineers in PSTS. (See table 1.2.)

Engineering graduates working as engineers are paid well.[9] Table 1.3 presents the real (2014 dollars) median salaries for all engineering fields in selected years between 2005 and 2014. Petroleum and computer hardware engineering are among the highest paid fields (over $100,000 in 2014), with civil engineering a consistently lower paid field (in the mid-$80,000 range during this period).

The different pay ranges and changes over time for selected engineering fields are shown in figure 1.1. Civil, industrial, and mechanical are lower-paid fields and show minimal increase in median wages over the decade, with no wage growth in the last period, 2011 to 2014. Petroleum engineer stands out as both a substantially higher-paying field and as the one occupation that experienced sharp increases in earnings (see Lynn, Salzman,

9. The median earnings of engineers in 2014 dollars presented in table 1.3 are all substantially above the annualized median earnings of all management and professional workers in 2014 reported by the Bureau of Labor Statistics (2015), where median weekly earnings for full-time workers are annualized by multiplying by fifty-two weeks.

Table 1.3 **Engineering graduate real (2014 dollars) median salaries by occupation**

Occupation	2005 ($)	2008 ($)	2011 ($)	2014 ($)
Petroleum	118,004	131,000	146,269	147,520
Computer hardware	105,665	110,153	106,676	110,650
Aerospace	103,580	103,336	109,317	107,700
Nuclear	109,931	109,680	110,675	104,630
Chemical	96,040	97,596	104,655	103,590
Mining and geological incl. mining safety	90,997	87,865	94,794	100,970
Electronics except computer	96,961	97,497	99,635	99,660
Marine and naval architects	90,088	85,677	96,541	99,160
Engineers, all other	94,028	97,948	97,099	96,350
Electrical	92,197	93,846	93,878	95,780
Biomedical	91,373	89,195	92,994	91,760
Materials	86,537	92,582	91,342	91,150
Mechanical	84,852	85,985	87,932	87,140
Civil	84,221	86,380	87,048	87,130
Environmental	85,724	85,732	87,711	86,340
Industrial	83,033	83,280	84,027	85,110
Health and safety	81,506	81,180	82,659	84,850
Agricultural	80,451	80,102	82,512	75,440
All engineers	90,518	91,978	93,659	93,626

Source: Authors' calculations from 2014, 2011, 2008, and 2005 OES.

and Kuehn, chapter 8, this volume).[10] Chemical engineering also showed increases, likely due to a small but significant number of chemical engineers working in the petroleum industry and paid substantially higher wages than other chemical engineers. Of note is that, with only a few exceptions, median earnings levels have shown little wage growth over the past decade. The wage levels would suggest that only in a few fields has there been growing demand for engineers.

From 1993 to 2013, no more than about half of workers with a degree in engineering actually reported that they were working as engineers, as compared to about one-third of all science, technology, engineering, and mathematics (STEM)-degree labor force participants who work in a STEM occupation (exclusive of social sciences where bachelor's degrees rarely confer professional status).[11] Of recent graduates, about two-thirds of those with four-year engineering degrees report they are in an engineering or other STEM occupation, as compared to only about a half of all STEM graduates who enter a STEM occupation (Salzman, Kuehn, and Lowell 2013; Salzman

10. See Lynn, Salzman, and Kuehn (chapter 8, this volume), for analysis of the changes in this occupation.

11. Since the wages in the previous tables and figure are only for those engineers working in an engineering occupation, they relate to only about half of all engineers in the workforce.

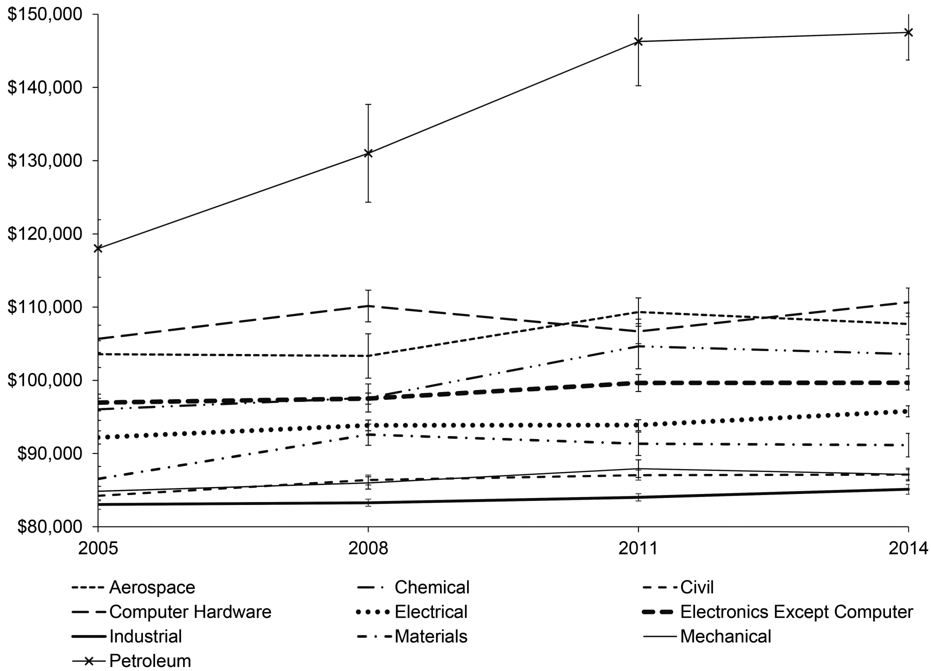

Fig. 1.1 Real earnings (2014 dollars) of engineers by selected fields, 2005–2014
Source: Authors' calculations from 2014, 2011, 2008, and 2005 OES.

2015).[12] This suggests that although many engineering graduates do not enter an engineering career, those who do persist in a STEM career at higher rates than graduates in other nonsocial science STEM fields. However, the employment prospects of engineers vary significantly by field.

The workforce size and changes over the past decade are shown in figure 1.2. Employment growth occurred in petroleum (Lynn, Salzman, and Kuehn, chapter 8, this volume), biomedical, mechanical, industrial, and electrical engineering fields. Aerospace and civil engineering changes reflect the cyclical changes in their respective fields, with civil engineering reflecting the construction expansion and then collapse, followed by a recovery at the end of the past decade.

1.2.1 Government Demand for Engineers

Government is a large employer of engineers, both directly as public employees (7.4 percent of all engineers in 2010 as reported in the OES statis-

12. Authors' tabulation of ACS data reported in U.S. Census Bureau (2012) and Salzman (2015).

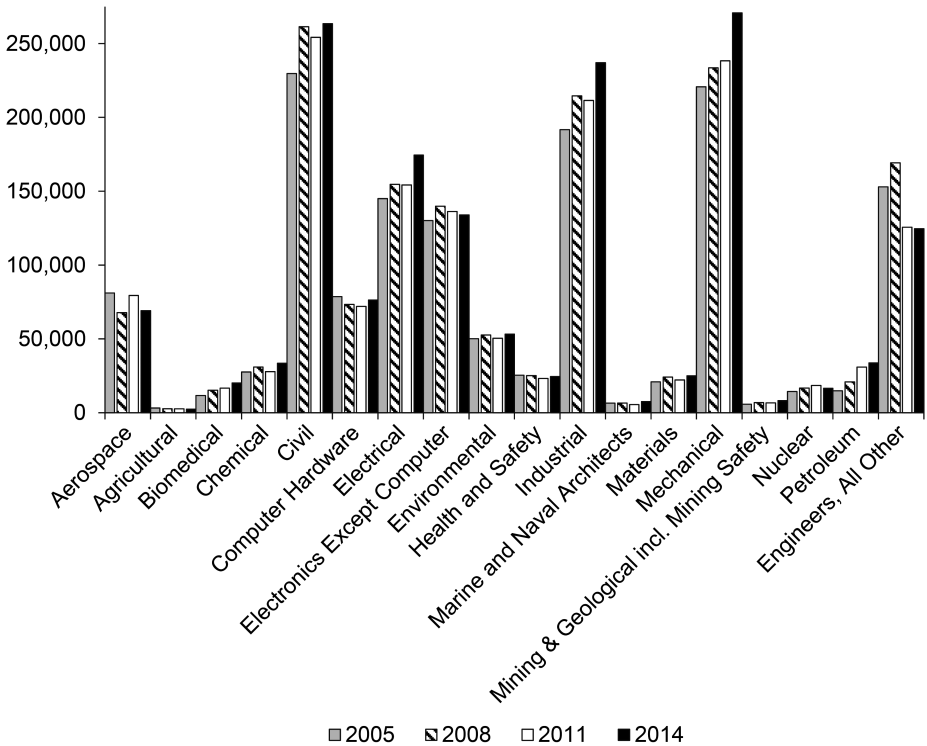

Fig. 1.2 Employment of engineers by occupation, 2005–2014
Source: Authors' calculations from 2014, 2011, 2008, and 2005 OES.

tics) and indirectly in private companies working on government contracts. In the post–World War II period, the federal government expanded its role as a significant funder of public infrastructure and research and development, maintaining a large standing military and expanding the role of science and engineering in defense strategy, from weapons development to espionage. Notable cases of sharp increases in the public demand for engineering labor that had a dramatic effect on the engineering labor market range from the interstate highway system to increased R&D for new military systems. Major defense investments began in the late 1970s in the Carter administration through the mid-1980s, when it appears military R&D slowed and defense-related engineering employment declined during the latter half of the Reagan administration.[13] Federal policymakers have thus viewed engi-

13. As discussed in section 1.3, military R&D that affects engineering employment may occur in a different cycle from overall military spending, preceding overall military budget increases by a number of years, and may not be paid for by the military until years after the defense

neers (and scientists) as essential to the military and economic strength of the nation.

Following World War II, policymakers have focused on programs that could develop the science and engineering workforce as a particular goal of more general government efforts to improve the education of the U.S. population. In doing so, federal policymakers shifted their approach to engineering labor supply from "markets-to-manpower" planning (Kaiser 2002). More generalized educational policies such as the GI Bill and the expansion of university funding also led to increasing numbers of students pursuing engineering as an occupational route off the farms and into the middle class. Manpower studies assessing the adequacy of the science and engineering workforce became commonplace across a variety of agencies, using more sophisticated modeling and forecast methods over time (McPherson 1986). Vannevar Bush's 1945 report *Science, the Endless Frontier* developed the vision for postwar government science policy that still influences policy today. Bush's discussions of the science and engineering workforce focused on the production of new scientists and engineers to support the expansion of science and engineering for the national defense and advancement of discovery and innovation. In 1953, the new National Science Foundation took on primary responsibility for monitoring the science and engineering workforce and the maintenance of a National Register of Scientific and Technical Personnel (National Science Foundation 1953).

The federal government developed a direct interest as an employer in the supply of engineers, as well as a more general policy interest in ensuring an adequate supply for industry in general, and military contractors in particular. Government commissions and agencies regularly assessed the

contractor incurs the expense, including the associated increase in employment. Fox (2011, 22), in his in-depth history of military procurement, notes that:

> There is often an earlier informal acquisition process that has its origin in defense laboratories or defense contractor firms, where engineers conceive of a new device or a new subsystem. Representatives of a firm may approach a military service, describe how they believe a device or subsystem will enhance the defense capability of the service, and then help the service prepare the justification and RFP to conduct a more formal study of the idea. This assistance nurtures the idea until it evolves into a military requirement.
>
> A defense firm wishing to obtain a contract to develop a new weapon system usually becomes involved in the program two to four years before a formal RFP is issued, or it is unlikely to qualify as a prospective contractor. This involvement generally means assisting the buying service in defining elements of the planned weapon system. The cost of conducting this initial work generally becomes part of contractors' overhead costs (for example, bid and proposal expense or independent research and development expense), which the Defense Department usually reimburses in part or in full.

The first phase of the military buildup during the early 1980s of the Reagan administration was accompanied by many reports of, and congressional investigations into, "fraud, waste, mismanagement and abuse" and various attempts to reform the procurement process (Fox 2011). It may be that the increased attention to military contractor practices also curtailed contractor R&D by the mid-1980s.

engineering workforce supply, and the resulting reports ranged from alarm at impending labor shortages[14] to empirical assessments that found supply to be adequate, fluctuating with cyclical changes in demand. In 1986 a report by the National Academy of Engineering on the effect of increased Reagan-era defense spending on the engineering labor market concluded that "evidence drawn from a variety of sources does not suggest pervasive or serious industrial shortages" (National Research Council 1986). The most recent report from the National Research Council (2012) on the STEM workforce supply for the Department of Defense, led by the same committee chairman of the earlier 2007 National Research Council report about impending shortages and crises in STEM, found the engineering, scientific, and technical workforce supply to be sufficient with the exception of cybersecurity experts, anthropologists, and linguists, for which the Department of Defense had unmet demand and difficulty recruiting.

The federal government is the primary source of government demand for weapons systems, biomedical and other research, and large infrastructure projects. State and local governments differ both in the scale and the nature of their engineering activities. These governments almost exclusively employ or contract with civil or environmental engineers for infrastructure projects and regulatory services. The skill sets of these engineers are generally more homogeneous, and they are more likely to work in smaller firms than in larger specialized firms that work on federal contracts. Table 1.4 presents the composition of the federal engineering workforce in 2010 and the federal government's share of the national engineering workforce by detailed occupational categories. Table 1.5 presents the same information for state and local governments.[15] Federally employed aerospace engineers make up less than 10 percent of the engineers directly employed by the federal government. A quarter of federally employed engineers have no specialized field identified at all. A similar share are electrical and electronics engineers (4.4 and 18 percent, respectively), with smaller proportions working as mechanical engineers (12 percent) and civil engineers (11 percent). In selected detailed occupations, the federal government employs a nontrivial

14. For example, the 1962 Gilliand panel reported that, "Impending shortages of talented, highly trained scientists and engineers threaten the successful fulfillment of vital national commitments. Unless remedial action is taken promptly, future needs for superior engineers, mathematicians, and physical scientists seriously outstrip supply" (President's Science Advisory Committee 1962, 1). A recent example is the National Academy's (2007, 3) *Rising above the Gathering Storm* report, which was "deeply concerned that the scientific and technological building blocks critical to our economic leadership are eroding at a time when many other nations are gathering strength."

15. The data is from the 2010 OES. Federal employment of engineers in the OES data from 2008 is of comparable magnitude to NSF estimates using data from the U.S. Office of Personnel Management (National Science Foundation 2008). Total public employment of engineers from the OES in 2006 is somewhat higher than from SESTAT (166,630 in the OES and 144,250 in SESTAT), potentially because of differences between self-reported occupational categories and occupations reported by employers. The SESTAT is also restricted to college degree holders, and a small share of engineers does not hold four-year college degrees.

Table 1.4 **Engineering occupations employed by federal governments in 2010**

Engineering occupation	Number	Percent of federal engineers in detailed occupation groups	Percent of engineers nationally working for federal government
Aerospace engineers	9,220	9	12
Agricultural engineers	400	0.4	16
Biomedical engineers	500	0.5	3.3
Chemical engineers	1,130	1.2	3.9
Civil engineers	10,630	11	4.3
Computer hardware engineers	4,430	5	7
Electrical engineers	4,260	4	2.9
Electronics engineers, except computer	17,790	18	13
Engineers, all other	25,450	26	18
Environmental engineers	3,800	3.9	8
Health and safety engineers, except mining	710	0.7	3.0
Industrial engineers	1,340	1.4	0.7
Marine engineers and naval architects	910	0.9	16
Materials engineers	1,320	1.4	6
Mechanical engineers	11,710	12.1	5
Mining and geological engineers	160	0.2	2.6
Nuclear engineers	2,730	2.8	15
Petroleum engineers	330	0.3	1.2
Total	96,820	100	7

Source: Authors' calculations from the 2010 OES.

Table 1.5 **Engineering occupations employed by state and local governments in 2010**

Engineering occupation	Number	Percent of state and local engineers in detailed occupation groups	Percent of engineers nationally working for state and local government
Aerospace engineers	0	0.0	0.0
Agricultural engineers	0	0.0	0.0
Biomedical engineers	40	0.0	0.3
Chemical engineers	110	0.1	0.4
Civil engineers	61,030	69	25
Computer hardware engineers	120	0.1	0.2
Electrical engineers	3,130	3.5	2.1
Electronics engineers, except computer	540	0.6	0.4
Engineers, all other	6,570	7	4.7
Environmental engineers	11,120	13	22
Health and safety engineers, except mining	2,940	3.3	13
Industrial engineers	510	0.6	0.3
Marine engineers and naval architects	70	0.1	1.2
Materials engineers	300	0.3	1.4
Mechanical engineers	1,950	2.2	0.8
Mining and geological engineers	410	0.5	7
Nuclear engineers	70	0.1	0.4
Petroleum engineers	0	0.0	0.0
Total	88,910	100	6

Source: Authors' calculations from the 2010 OES.

share of all engineers. For example, although less than 1 percent of federal engineers are marine engineers, the estimated 910 federal workers make up almost 16 percent of that engineering occupation nationally.

The state and local engineering workforce is far less occupationally diverse. Sixty-nine percent are civil engineers and 13 percent are environmental engineers. State and local governments employ almost one-quarter of civil engineers and over one-fifth of environmental engineers, nationally.

The most detailed information on direct federal employment of scientists and engineers comes from internal personnel data provided by the U.S. Office of Personnel Management and the Defense Manpower Data Center and published on an irregular basis by NSF. These data suggest that federal engineering employment after the Cold War peaked at just under 98,000 in 1992, dropping over the course of the decade to a low of just over 82,600 in 2000. After 2000, federal engineering employment grew steadily again, reaching a peak of just over 87,000 in 2004. NSF has not published updates on these federal employment figures for years more recent than 2005. The distribution of these changes are relatively even across fields; no field contributed an especially disproportionate amount to the change.[16]

The share of engineering graduates working in an engineering occupation that is either employed by the government or working on a government contract or grant has remained relatively steady during the post–Cold War period, ranging from around 36 to 39 percent of the total (table 1.6), with most of those engineers working on government contracts rather than directly for the government. The share of these engineers working on government contracts (rather than as direct employees) has increased steadily over time from 60 percent in 1993 to 71 percent in 2013. These engineers may not be exclusively doing government work, but may also have private contracts; to the extent that engineers working as contractors are not exclusively working as full-time equivalent government contractors, the employment shift could be overstating the full-time equivalent engineering employment on federal work (either on a contract or grant or in direct federal employment).

The government is likely to continue to play an important role in the demand for engineers, particularly in specialized occupations like aerospace through defense purchases, nuclear engineering directly through defense contracts and indirectly through roles in regulation and any issuing of new reactor permits, and civil engineering through public works projects, particularly at the state and local level. Funding levels for the National Institutes of Health, alongside growth of medical devices firms, will be an important force shaping the demand for biomedical engineers inside and outside of government. The extent of continued demand for civil and environmental engineers by state and local governments is likely to be highly contingent on government infrastructure investments as well as private construction.

16. See the National Science Foundation's (1995, 2005, 2008) reports on federal scientists and engineers.

Table 1.6 **Engineering graduates working as engineers and on government work (direct or on contract/grant)**

	(1) Percent employed by the government or on government contract (%)	(2) Number employed by the government or on government contract	(3) Contract share of government engineers (share of column [1]) (%)	(4) Number employed on government contract
1993	38.07	382,196	60	227,799
1995	36.87	382,489	62	238,948
1997	34.75	374,507	63	237,522
1999	—	—	—	—
2003	36.27	410,683	68	277,857
2006	36.80	454,798	70	316,147
2008	37.14	458,097	70	321,624
2010	38.29	432,805	70	302,650
2013	39.82	456,965	71	326,311

Source: Authors' calculations from SESTAT 1993–2013. The sample is restricted to employed respondents who earned a bachelor's degree or higher in engineering and earned their highest degree in the United States, and is weighted to be nationally representative. The 1999 SESTAT is excluded because it does not specify whether respondents work on government contracts. The SESTAT asks survey respondents, "was any of your work during [year] supported by contracts or grants from the U.S. government?" The SESTAT engineer population is 1,147,000, compared to the ACS engineer population of 1,950,000, due to differences in sampling and population coverage; the ACS population is all who self-report work in an engineering occupation, regardless of degree level or where the degree was awarded.

1.2.2 Retirement and Replacement Demand

A concern about the engineering labor market is whether large worker attrition due to retirement and older workers leaving the field can be filled. Even in engineering fields that are not growing, replacement demand may be a major source of demand for new graduates. The impending retirement of baby boomers has led to concern that not enough graduates are being produced to replace retirees and that transferring knowledge from more experienced to less experienced engineers will pose problems for engineering continuity (Gibson et al. 2003). Freeman (2007) provides an empirical framework for investigating this issue and finds that "demographic changes have not historically been consistently associated with changes in labor market conditions, even for the young workers whose position is most sensitive to changing market realities." Freeman (2007, 5) assesses replacement demand for all occupations and we use his empirical framework to analyze the engineering labor market specifically. The analysis finds evidence that demand for younger engineers is not related to aging in the engineering workforce. This result is somewhat weaker than Freeman's analysis of all occupations, which found a negative relationship between the proportion of workers over age fifty-five in an occupation and growth of younger cohorts in those fields. He concludes that older workers are concentrated in occu-

Table 1.7 **Estimated relationships between occupational employment of engineering graduates older than fifty-five in 2003 and employment of other age groups**

	Age group in 2013		
	25–34	35–44	45–54
Share of workers age fifty-five and older, 2003	0.085	0.035	0.366***
	(0.155)	(0.066)	(0.085)
Share of workers in specified group, 2003	0.857***	0.327***	0.333***
	(0.149)	(0.082)	(0.126)
Constant	0.093*	0.126***	0.102***
	(0.055)	(0.036)	(0.036)
R^2	0.408	0.142	0.190
Observations	118	118	118

Source: Authors' calculations from SESTAT 2003 and 2013. The sample is restricted to employed respondents who earned a bachelor's degree or higher in engineering and earned their highest degree in the United States, and is weighted to be nationally representative.

***Significant at the 1 percent level.

*Significant at the 10 percent level.

pations with declining employment, and thus not replaced; employment demand for younger workers is, instead, predominately in growing occupations. While our results do not suggest that older workers are concentrated in labor markets that are in decline, they also do not suggest a major role for replacement demand in the market for new engineers.

Occupation-sector-educational-attainment cells serve as the unit of analysis in the regressions in table 1.7, which estimate the employment share of various age groups in 2013 on that specified group's employment share a decade earlier in 2003 and the share age fifty-five and older in 2003. For example, one cell is "electrical engineers in the private sector with master's degrees," while another is "electrical engineers in the public sector with master's degrees." Occupation-sector-education cells with fewer than twenty observations in the 2013 SESTAT were omitted from the analysis to ensure the reliability of the estimates of employment shares. One hundred and eighteen occupation-sector-education cells were available in both 2003 and 2013. As with other analyses using the SESTAT data, the sample is restricted to holders of engineering degrees who earned their highest degree in the United States. Occupations that are in equilibrium, where new labor supply is sufficient for meeting replacement demand, would have employment shares for each age group in 2013 that are comparable to the employment shares of that age group in 2003. We would expect such an equilibrium to have significant coefficients for their specified age group, and no significant relationship between the employment share of engineers that are age fifty-five or older. In an occupation that is experiencing the retirement of a large population of older workers, and responding with a major recruitment of younger workers, we would expect a positive association between the employment share of engineers that are fifty-five or older in 2003 and the worker share of a younger age group in 2013.

The regressions provide no evidence that the share of younger workers (ages twenty-five to thirty-five) increases in 2013 when a larger share of the occupation-sector-education-group's workers are over the age of fifty-five in 2003. The regressions show a larger positive and statistically significant relationship between the share of workers older than fifty-five in 2003 and the share of workers age forty-five to fifty-five in 2013. This finding is consistent with a declining occupation group rather than an occupation making a major effort to recruit young workers to replace retiring workers. As older workers in a declining occupation retire and few younger workers are hired because there is no expectation of a future expansion of the occupation, the remaining middle-aged workers represent an increasing share of the workforce.

The finding that in general retiree replacement demand is not an important source of demand for new engineers does not imply that in all cases replacement demand is negligible. Petroleum engineering provides a recent example of an occupation with an aging workforce that, in combination with new industry growth due to technology innovation and product demand, until recent years was growing rapidly and drew many new engineering graduates into the field with the incentive of higher salaries. Analysis of the petroleum engineering industry is discussed in more detail by Lynn, Salzman, and Kuehn (chapter 8, this volume).

1.3 Engineering Education and the Supply of New Engineers

Engineers require specialized training, predominately at the undergraduate level, though in some cases at the graduate level. As with most specialized professions, nonengineers cannot be easily substituted for engineers to meet demand. While conceivably former engineers can move back into the occupation from other occupations, this sort of labor "backtracking" is relatively rare (Biddle and Roberts 1994). Immigrants trained abroad can also add to the stock of engineers, but the primary source of new engineering labor is through the entrance of new graduates into the labor market (some of whom may be immigrants themselves). This section presents trends in the supply of new engineering graduates in the aggregate and by field of engineering. New engineer supply trends are tracked using data from the Integrated Postsecondary Education Data System (IPEDS), which collects detailed annual enrollment and graduation information on all postsecondary institutions that accept federal financial aid (approximately 6,700 institutions). Data come from engineering degree programs and specifically exclude computer science graduates and "engineering technology" programs that primarily produce software engineers and technicians, respectively, rather than engineers. The IPEDS data are made publically available from 1980 to the present in detailed institution-level files and from 1966 to the present at a more aggregated level.[17]

1.3.1 Bachelor's Degree Trends

Figure 1.3 presents data on engineering graduates from 1966 to 2013 by the level of degree awarded. Bachelor's degrees are measured according to the scale on the left axis, and range between 60,000 and 90,000 degrees awarded every year during the past thirty years since the mid-1980s, after almost doubling between 1976 and 1985. In this figure, graduate and associate's degrees are shown on the right axis, reflecting the much smaller number of graduates at those degree levels. Master's degree awards have been increasing steadily since 1966, with rapid growth late in the first decade of the twenty-first century. Almost 45,000 master's degrees in engineering were awarded in 2013, triple the number of awards that were typically awarded annually between 1966 and 1980. Considerably fewer doctoral and associate's degrees have been produced annually during this period, with no discernable increase in these awards over time.

There are five distinct periods in the bachelor's degree award trend in figure 1.3. First, between 1966 and 1976, bachelor's degree awards fluctuated between 40,000 to 50,000 annually, ending at the same level as the beginning of this ten-year period. Then, between 1976 and 1985, bachelor's degrees in engineering increased from under 40,000 to almost 78,000. This period of growth was followed by a decline in awards through the late 1980s to somewhat more than 60,000 bachelor's degrees produced annually by 1990. After 1990, engineering awards stabilized at a level slightly higher than 60,000 awards per year, and maintained this level through the dot-com bubble in the late 1990s, until approximately 2001.

Since 2001, the number of bachelor's degrees in engineering awarded annually have steadily increased, reaching the level of degrees awarded in 1985 (roughly 70,000 per year) in 2008 and then surpassing it in 2011; by 2013, almost 89,000 bachelor's degrees in engineering were awarded. Graduate degrees in engineering have experienced more consistent growth since 1980 than bachelor's degrees. Between 1981 and 2004, a period when there were almost no net gains in bachelor's degrees awarded, the number of master's degrees awarded in engineering doubled from 16,000 to nearly 34,000. Doctorates more than doubled from 2,500 to almost 6,000 over this period.

Each of these degree levels can be decomposed into more detailed engineering fields in which degrees are awarded. As discussed earlier, "engi-

17. Engineering fields and programs in this section are identified using the IPEDS Classification of Instructional Programs, or CIP codes. These codes may not reflect organizational structure of the departments themselves in all cases.

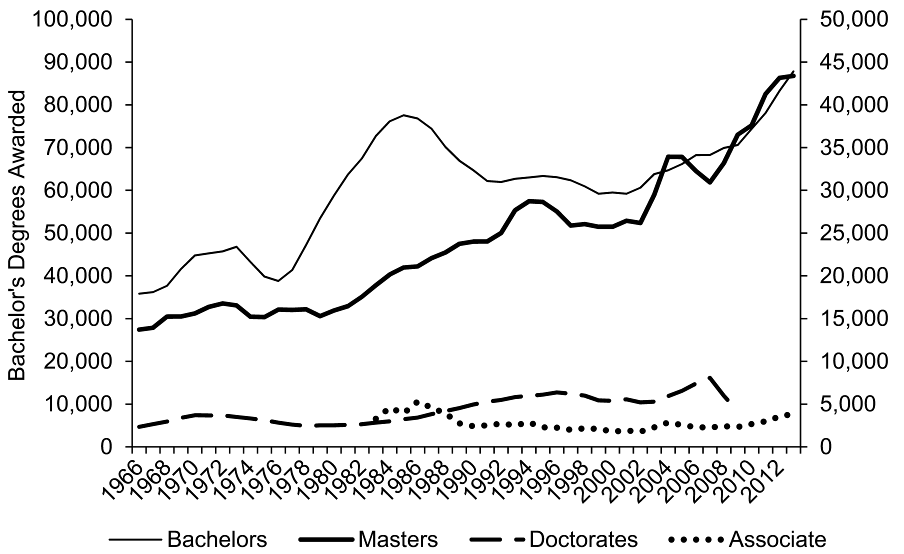

Fig. 1.3 Engineering graduates, 1966–2013

Source: Authors' calculations from engineering degrees in the IPEDS, 1966–2013.

Note: Bachelor's degrees are shown on the left axis; doctoral, master's, and associate's degrees are shown on the right axis.

neering" is an aggregate occupational category that comprises a number of distinct fields that may have some common educational requirements but are occupationally quite different. An electrical engineer, for example, may be designing semiconductors while a civil engineer is designing buildings, with little commonality in skills, technology, or knowledge content, and working in industries that may have very different business and employment dynamics. Analysis of supply and demand thus requires a more disaggregated analysis of the major engineering fields.

In this section we examine the trends in each of the major engineering occupations identifiable back to 1966: electrical, which is a field largely supplying the manufacturing sector and the information technology (IT) and computer industries; mechanical, which is also predominately in manufacturing, concentrating on the design and maintenance of manufacturing equipment and systems; civil, which supplies the construction sector and the independent professional-services sector (e.g., architectural firms and engineering consulting firms) and local governments; and chemical, industrial, aerospace, and materials engineering, which are all concentrated in manufacturing. All other engineering fields are grouped in an "other" category, which includes a range of specialty fields from petroleum engineering to computer engineering and biomedical engineering. We also look at detailed occupations that form a relatively small portion of the total but are important growth sectors: biomedical engineering, which has grown more recently and appears to be a route both into engineering (e.g., medical devices) and, to some extent, medical school; and computer engineering, which grew rapidly over the late 1990s but has since experienced a decline. Together, engineering degrees in these six fields (electrical, civil, chemical, mechanical, computer, biomedical) accounted for 77 percent of all engineering bachelor's degrees awarded in 2008.

Trends in bachelor's degrees awarded in these six fields are presented in figure 1.4. A major driver of the increase in engineering graduates in the mid-1980s was the high production of electrical engineering degrees, which made up a third of all engineering bachelor's degrees in that decade. Between 1976 and 1987, the number of electrical engineering bachelor's degrees awarded increased by 270 percent, from just under 10,000 annually in 1976 to almost 27,000 in 1987. Annual electrical engineering awards went into a period of sharp decline after 1987, accounting for a large share of the decline in total engineering degree awards during this period. Between 1987 and 1996, the number of electrical engineering bachelor's degrees awarded annually in the United States fell by over 10,000. Mechanical engineering degree awards track electrical engineering degree awards, but to a more modest extent. Mechanical engineering grew rapidly in the late 1970s and early 1980s, and then it moderated for the next several decades. The decline in mechanical engineering awards after its peak in the mid-1980s from 17,200 in 1985 to 14,263 in 1991 was not as steep as the decline in electrical engineering.

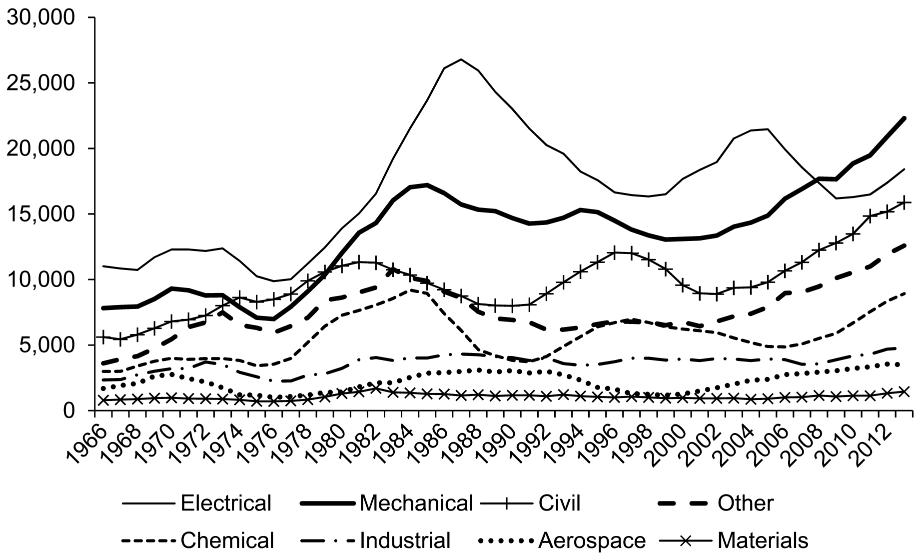

Fig. 1.4 Engineering bachelor's degree awards, 1966–2013
Source: Authors' calculations from engineering degrees in the IPEDS, 1966–2013.

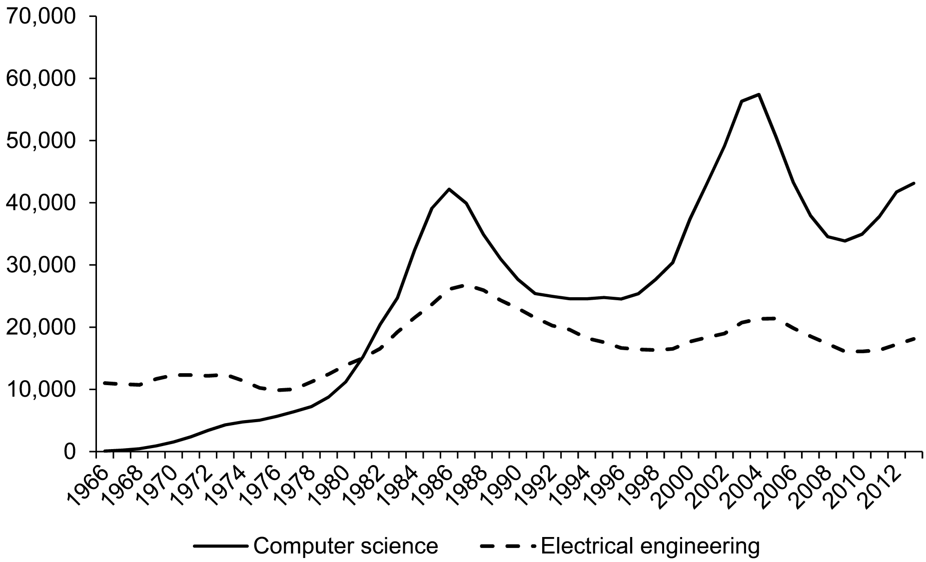

Fig. 1.5 Computer science and electrical engineering bachelor's degrees, 1966–2013

Source: Authors' calculations from computer science and engineering degrees in the IPEDS, 1966–2013.

The increase in these engineering degrees was countercyclical during this period: gross domestic product (GDP) growth declined beginning around 1977 until the early 1980s and overall unemployment increased, reflecting the downward trajectory of rates of GDP growth. Only in the late 1980s does the number of engineering graduates decline along with rising unemployment and declining GDP growth rates. Between 1970 and 1986, bachelor's degrees in computer science increased by almost thirtyfold from 1,500 to 42,200 awards, while over the same period electrical engineering degrees doubled from 12,300 awards to 26,100 (see figure 1.5). Graduates in electrical engineering increased significantly during this period relative to other engineering fields, but its growth and size were eclipsed by those of computer science. Between 1987 and 1996, the number of electrical engineering bachelor's degrees awarded annually in the United States fell by over 10,000, accounting for the major share of overall engineering degree declines. Computer science also experienced a decline in bachelor's degrees awarded during the late 1980s and early 1990s, as well as the early twenty-first century (see figure 1.5), falling from a peak of 42,200 in 1986 to 24,600 in 1994.[18]

The strong growth in these engineering fields while the overall economy

18. Authors' calculations of degrees from the IPEDS.

was in decline during the 1970s and early 1980s appears to be due largely to the growth and change in military technology development and in the semiconductor industry and secondarily by the growing personal computer industry, though the size of its workforce was small during this period. The early to mid-1970s was a period of economic stagnation and decline in demand for engineering. Defense spending declined beginning in the early 1970s, and continued its decline following the complete withdrawal from the Vietnam War in 1975 and the overall economic stagnation following the 1973 Organization of Petroleum Exporting Countries' oil embargo and the 1973–1975 recession. Defense spending declined by 30 percent (in constant dollars) from 1968 to 1973, with a further 10 percent decline by 1976, ending that ten-year period at 60 percent of 1968 spending levels. This occurred alongside civilian aircraft sales declines of nearly 25 percent from 1968 to 1971, with overall job losses of 900,000 in the defense sector from 1969 to 1971, and job losses of 580,000 in the aerospace industries from 1968 to 1972; by 1973, employment in the space program was left at one-third the size of its 1965 workforce (U.S. Congress, Office of Technology Assessment 1992, 106).

In the late 1970s through the mid-1980s, the number of engineering graduates increases in an apparent countercyclical pattern to the overall economy, but it does follow the growth in military technology development, electronics, and computer industries. Although engineering graduation rates reflect changes in military spending on R&D, they do not closely reflect the trajectory of *overall* military expenditures because engineering employment for military technology can follow a different pattern from that for overall defense spending. Technology development will begin before actual production of new systems (sometimes even before the military programs are fully funded) and the involved engineers and other developers may be laid off once the systems go into production, long before production and overall spending declines, or when systems are cancelled during development (U.S. Congress, Office of Technology Assessment 1992). Engineering employment, and electronics engineer and computer scientist employment in particular, for the two decades following the late 1970s, appears to be driven largely by the growth of the semiconductor industry; in addition to demand for semiconductors, development of other electronic technologies using semiconductors, and especially the development trajectory of military systems, as well as changes in the fortunes of the semiconductor industry during this period, drove the engineering and computer science employment cycles.

During the late 1960s through the early to mid-1980s, civilian industries were not expanding their engineering workforces and many industries, especially aerospace, were in severe decline, as noted above. However, even while overall military spending was in decline and then stabilized just before the large Reagan-era Star Wars military program (Strategic Defense Initiative [SDI]) was established in 1984, new technologies were being developed by the military. The systems developed beginning in the late 1970s represented a significant change in technology—they were systems that shifted to more electronics, "black-box" maintenance designs (in which components were swapped out to be repaired off the battlefield), and generally required much greater levels of technical support and maintenance than older systems, alongside a shift to using more nonmilitary personnel contractors to support military missions. The fundamental change to greater electronics-based technology was reflected in an Air Force general's quip: "In the past, the Air Force used to buy airplanes and add electronics. Today the Air Force buys computers and puts wings on them." Forty percent or more of the funds for Department of Defense aircraft are spent on electronics equipment (Fox 2011).

The expansion of military systems beginning in the late 1970s also increased in anticipation of greater military spending in the 1980s, "long before Reagan surprised most of the nation with his ode to Star Wars" (Hiatt and Atkinson 1985). Firms involved in military technology development "had been pushing for new 'defensive' systems prior to their becoming politically popular in the 1980s. Indeed, the big aerospace firms already had done substantial SDI-related work in the 1970s" (DiFilippo 1990). The genesis of SDI was in part the outcome of laser technology development in the 1970s, which was heavily funded by the Department of Defense, spending $100 million a year by 1981 (DiFilippo 1990, 114). It was laser technology that convinced the hydrogen bomb developer Edward Teller and General Daniel Graham, "who identifies himself as the 'midwife' of Star Wars" (DiFilippo 1990, 114), that ballistic missile defense was technically possible. (Teller became director of a private laser technology firm that relied on Department of Defense funding as well as becoming a member of the White House Science Council where, in 1982, he began proposing SDI development to President Reagan [DiFilippo 1990, 115].) In 1981 Rockwell International wrote in its company brochure "Space defense systems will be developed in the near future" and "companies unleashed their engineers in a hunt for new weapons, new technology" (Hiatt and Atkinson 1985). And this was true throughout the branches, as two journalists and industry observers noted in 1985: "The Army has both boots planted firmly in the electronic age, following the path blazed by the Air Force 15 years ago in fielding weapons less mechanical and more reliant on computers and microcircuits" (Atkinson and Hiatt 1985). Electronics and computer technology were also being diffused throughout other military applications, in simulators for training and in simulations analysis and technology development, widespread in the military by the end of the 1970s (Chait et al. 2007).[19] The

19. In this defense report, "Project Hindsight Revisited," it is noted that "the Abrams program [in the 1970s] called for gun ranges, armor testing ranges, special facilities for testing armor and munitions containing depleted uranium (DU), test tracks, materials laboratories, and visualization techniques for measuring the behavior of munitions at very high speeds and

American Society for Mechanical Engineers reportedly offered seminars for "engineering professionals [to] learn how to get in on the ground floor of the state-of-the-art cornucopia" (Hiatt and Atkinson, 1985). A U.S. investment banking defense analyst said (as cited in DiFilippo [1990, 117]), "SDI is the future of the defense industry. No competitive high-tech company can afford not to be part of SDI."

The shift to employment in the electronics occupations *within* the military (this includes electronics engineers, but also other electronics occupations) continued the post–World War II trend, though with a sharp increase in the late 1970s, with electronics occupations accounting for one in twenty enlisted jobs at the end of World War II to one in five enlisted jobs by the early 1980s, and it "accounts for all the growth in the technical occupations since 1957 . . . the increase in the proportion of electronics technicians in the armed forces closely parallels changes in the electronics content of military equipment (as measured by cost), which has grown from an estimated 10 to 20 percent in the 1950s, to 20 to 30 percent in the late 1960s/early 1970s, and to nearly 40 percent by 1983" (Binkin 1988, 188). By the late 1980s, 45 percent of all engineers working in defense were electrical engineers (as compared to only 28 percent of nondefense engineers who were electrical engineers [U.S. Congress, Office of Technology Assessment 1992, 104]).

Important to note is that the increase in the military was occurring while there were declines in civilian-sector employment; the military increases absorbed declines in other industries, thus increasing the share of military-dependent employment within all engineering employment. Although this countercyclical employment was occurring throughout engineering fields, it was a particularly sharp change in electrical engineering and computer science fields because of the dramatic change in the types of technology being developed, toward greater use of electronics. For example, during the airline industry's financial problems in the 1970s through the 1980s, civilian aerospace purchases were in steep decline and the large increase in military aerospace development and acquisition led to only a 2 percent overall increase in aerospace output during the early 1980s. However, "the defense share of aircraft output equaled 66 percent in 1985, compared with 43 percent in 1977. The aircraft and missile engine industry showed a similar increase in defense market share, rising from 47 to 78 percent between 1977 and 1985" (Henry and Oliver 1987, 6).

The semiconductor industry was a key industry in the electronic component supply chain for these military systems and, in fact, much of the electronic technology development (systems, components, and overall R&D)

during penetration of targets. Also, much of the work in the four systems we studied relied on advanced computers for modeling physical phenomena, such as the aeromechanics of the helicopter, finite element analysis of the composite sabot for the Abrams' kinetic energy rounds, and firing tests" (Chait et al. 2007, 20).

was the result of defense department investment during the 1970s. In addition, although the overall economy was stagnant throughout this period, it was a period of rapid growth for the semiconductor and electronics industries and the growth of the West Coast and Southwest electronics firms: "In just two years, from 1978 to 1980, the nation's semiconductor manufacturing capacity doubled" (Saxenian 1996, 87). During the first part of the 1980s, it was the semiconductor and microcomputer industry that drove much of the private-sector growth in the West and Southwest, whereas in the East Coast, particularly in the Route 128 region, the late 1970s and early 1980s was the height of the minicomputer industry. Between 1975 and 1985, Silicon Valley added nearly 150,000 jobs (total employment) before employment leveled off and then declined; in the Route 128 area, about 100,000 jobs were added during this period and then employment declined sharply (Saxenian 1996, 3, 99).

In the mid-1980s, several changes led to a dramatic reversal of fortune for the electronics industry. In semiconductors, foreign firms expanded their market share, with U.S. memory producers market share declining in 1986 to one-third of their dominant 75 percent market share in 1980 (Brown and Linden 2011, 17) and similar declines in other segments of chip manufacturing.[20] Although U.S. firms' actual production still increased through the 1980s, the declining market share and increased productivity (increasing annually by 13 percent from 1986 to 1992) presumably created caution about future domestic expansion and hiring in the face of intensifying foreign competition and their steep decline in market share; as one analyst report explains, "U.S. firms increased output without increasing employment by adopting new technologies that made U.S. semiconductor manufacturing more capital-intensive and productive and by transferring labor-intensive manufacturing abroad" (Malison 1993, 6). In Silicon Valley, the employment decline started in 1985 and occurred rapidly; 20 percent of all semiconductor employees lost their jobs and only three firms remained in dynamic random-access memory production by 1986, leading to "the worst recession in Silicon Valley history" (Saxenian 1996, 89; DiFilippo 1990, 64). From 1984 to 1995 the computer-manufacturing industry lost 32 percent of its workforce, falling at an annual rate of 3 percent (Warnke 1996, 18–23; Moris 1996). The minicomputer industry, based in the Route 128 region outside Boston, went into steep decline as demand shifted from minicomputers to personal computers and workstations. Although Silicon

20. "From a leading share of almost 62 percent in 1980, U.S. chipmakers lost roughly 25 percent of the global market over the next nine years, declining to a low point of 37 percent by 1989. Japanese semiconductor firms by 1989 accounted for more than half of global semiconductor revenues . . . Japanese semiconductor equipment manufacturers increased their global market share from less than 20 percent in 1980 to almost 50 percent in 1990, largely at the expense of U.S. equipment firms, whose market share declined from roughly 75 percent to less than 45 percent during the same period" (VLSI Research 1998, cited in National Research Council [1999], 251–52).

Valley recovered in the late 1980s, elsewhere the loss was permanent in the minicomputer industry and some other segments of the semiconductor and consumer electronics industries.

The decline of the semiconductor industry as market share was lost to foreign competitors, the decline of the minicomputer industry, and the end of R&D funding for Star Wars[21] all happened in the mid-1980s. It was thus the shifting fortunes of several industries occurring around the same time that led to the precipitous drop in demand for electrical engineering and computer science graduates.

Although the decline in engineering and computer science graduates precedes the decline in overall Star Wars spending, as noted above engineering is more dependent on R&D spending patterns than on the overall budget. Research and development spending may diverge from overall spending in preceding both the increases and the declines since engineering will increase before production and then may decline well before decreases in production and overall spending.[22] The demand for new electrical engineering and computer science graduates may have been satisfied during the rapid expansion of the 1982–1984 period with little or no additional hiring after that period. The 1986 peak in electrical engineering graduates would be consistent with the cobweb model of labor market adjustment, lagging by about two years changes in the actual labor market demand. The rise and decline of electrical engineering bachelor's degrees coincides with trends in salaries earned by both electrical engineering and computer science majors, which increased in the early 1980s and fell in the mid-1980s.

The most notable characteristic in the trends of civil, chemical, and other engineering bachelor's degrees during this time period was a modest business cycle procyclicality, particularly in the last thirty years, with peaks in the mid-1980s and late 1990s and troughs in 1990 and 1991. The procyclicality of the supply of graduates in these fields is attributable to at least two factors. First, college enrollment increases during periods of macroeconomic weakness as youth seek alternatives to poor employment prospects. These

21. The majority of the 1980s Star Wars and other military growth in R&D spending and increase in scientific and technical personnel in the military was during the 1982–1984 period, and "the rapid military buildup that began in the early 1980s and that includes increasing expenditures for SDI, had a very noticeable growth effect on scientific and engineering employment . . . defense requirements represent a significant fraction of overall employment in high technology industries" (DiFilippo 1990, 120).

22. For example, "[m]any of the biggest defense programs of the 1980s (e.g., General Dynamics's F-16 and McDonnell Douglas's F-15 fighter aircraft for the Air Force, Grumman's F-14 for the Navy, and General Dynamics's M1A2 tank) are coming to an end and few new programs are on the horizon to replace them, which means engineers can be let go while many production workers are still needed. Also, engineers are more heavily affected by the termination of new systems in their development stage. For example, the cancellation of the Navy's next generation attack jet, the A-12, caused the immediate dismissal of 7,000 workers, half of whom were engineers. In this case, the engineers were laid off before most of the production workers were even assigned to the program" (U.S. Congress, Office of Technology Assessment 1992, 104).

enrollees eventually graduate, usually four to six years later, in a labor market that is stronger as a result of economic recovery. Degree completion trends, as opposed to countercyclical enrollment trends, are therefore relatively procyclical. However, anticipation of future growth can also attract students to fields that provide skills in demand during economic recoveries. Civil and chemical engineering track the overall business cycle quite closely, but in other industry fields occupation-specific cycles diverge from the overall economic cycle and affect engineering labor markets and trends that may not mirror the overall economy.

The relative prominence of various engineering fields has shifted over time. While far more electrical engineers were supplied by four-year degree programs in the 1980s than any other field, in the last several years of available data nearly as many students graduated with a bachelor's degree in civil engineering as in electrical engineering (15,900 and 18,400, respectively) in 2013. Mechanical engineering degrees actually exceeded electrical engineering degree awards by 2008. In 1987, a peak of 36 percent of all engineering bachelor's degrees were in electrical engineering and over three times as many engineering graduates were earning an electrical engineering degree as a civil engineering degree. By 2013, 21 percent of all engineering graduates earned a degree in electrical engineering. In 2008, mechanical, civil, and chemical engineering degrees alone made up almost half of all engineering bachelor's degrees.

Two smaller fields that are not shown separately in figure 1.4, computer and biomedical engineering, are of interest because of their recent and prospective growth.[23] Neither exhibits the cyclicality of mechanical, chemical, or civil engineering for most of the period since 1980. Instead, each of these fields is characterized by steady secular growth, with particularly strong growth after 2000. Computer engineering degrees peaked in 2004, likely reflecting declining enrollments after the bursting of the dot-com bubble of the late 1990s through about 2001. Computer engineering programs primarily offer training in hardware engineering. Software engineers, who were even more exposed to the dot-com bubble and bust, would be more likely to hold computer science degrees (though only one-quarter of the IT workforce hold a computer science degree, and over one-third do not hold any four-year degree). Software engineers are not considered in this chapter. Unlike computer engineering awards, biomedical awards continued to increase after the dot-com bust and through the 2001 recession, buoyed by advances in genetics such as successful sequencing of the human genome in 2000, strong growth in health care and pharmaceuticals, and increased funding of medical research by the National Institutes of Health. Biomedical engineering degrees have also emerged as an alternate route to medical

23. This discussion relies on more detailed IPEDS data, not shown here, that is only available from the late 1980s to the present.

school, due to the development of advanced medical equipment (MRI, CAT, and other diagnostic equipment) that became widely used during this period. Linsenmeier (2003) points out that biomedical engineering majors have one of the highest acceptance rates to medical school of any major.

1.3.2 Graduate Degree Trends

While shifts in demand, cobweb dynamics, the business cycle, and new markets opened by technological advances shaped the fluctuations in bachelor's degrees over the last thirty years, there was much steadier growth in graduate education in engineering. This trend is comparable to trends in master's degrees outside of engineering, which have also grown continuously over the last fifty years.[24] Since 1966, the number of master's degrees in engineering awarded annually has more than tripled, while doctorates have increased by more than 75 percent. Master's degrees increased steadily since the late 1970s, with the exception of a drop following the post–Cold War decline in U.S. military spending and steep rise and subsequent decline lagging the dot-com bubble. Trends in master's awards in the same engineering field highlighted for bachelor's degrees are presented in figure 1.6. The difference between the trajectories of master's degrees and bachelor's degrees in electrical engineering is perhaps the starkest, with a reasonably steady increase in master's degrees in the field during periods of considerable declines in bachelor's degrees. It is likely that the increase in master's degrees reflected the poor job market and bachelor's degree graduates continuing their education because they were unable to find jobs. There is a slight cyclicality in the mechanical and civil engineering award trends, but a pattern of steady growth is found consistently across all fields.

A graduate degree in engineering is different from a graduate degree in other sciences in that it functions more as a professional, and less as an academic, degree than is the case in nonengineering fields. Individuals holding graduate degrees in engineering are much less likely to work in academia than those holding graduate degrees in biology, chemistry, and physics. Twenty-seven percent of those with doctorates in engineering in 2010 were employed in postsecondary education, compared to 47 percent of those with a doctorate in one of the natural sciences. The disparity is comparable for master's degrees. Among the population of terminal engineering master's degree holders, almost 7 percent worked in postsecondary education in 2008 (with 82 percent in the private sector), while almost 21 percent of those holding terminal master's degrees in the natural sciences work in postsecondary education. Terminal master's degree holders working in postsecondary education do research and teach at high rates, with holders of master's degrees in engineering somewhat more likely to be doing research and less likely

24. Master's degrees generally more than doubled between 1980 and 2008, from 299,095 to 631,711 awards.

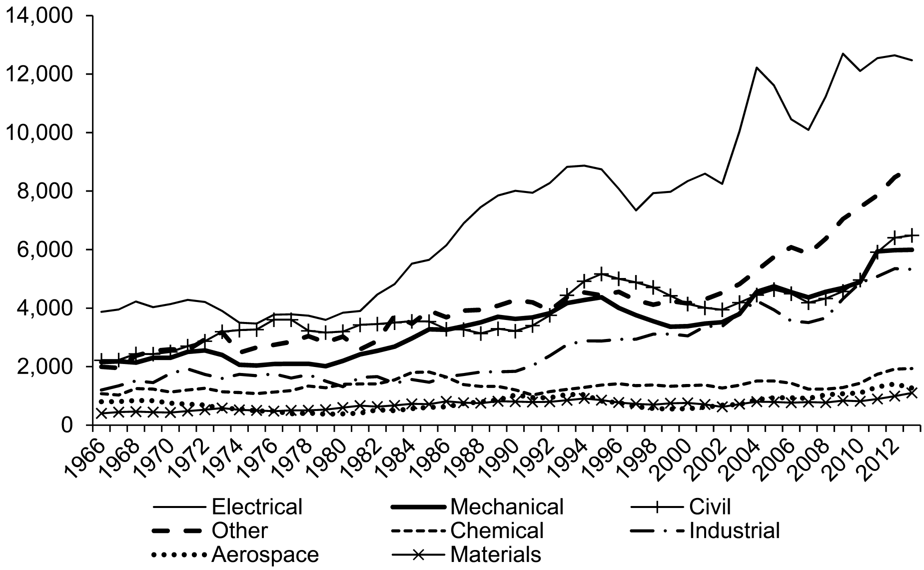

Fig. 1.6 Engineering master's degree awards, 1966–2013
Source: Authors' calculations from engineering degrees in the IPEDS, 1966–2013.

to be teaching than their natural science counterparts. It is unclear from the data, although quite plausible, that master's degree holders working in postsecondary education are primarily employed by community colleges.[25]

1.3.3 Engineering Education Demographics

Engineering is often noted as a field that has made slow progress in achieving racial, ethnic, and gender diversity. Some STEM fields such as science and math have made significant gains in gender parity to the extent that most science fields are at or above gender parity and math is close to parity, with women consistently obtaining between 42 and 48 percent of bachelor's math degrees since the 1970s. By contrast, the share of historically underrepresented African Americans, Hispanics, and other minorities has increased more slowly. The racial and ethnic composition of engineering bachelor's awards is provided in figure 1.7, with the white non-Hispanic share measured on the right axis, and all other categories on the left axis. Whites made up the majority of engineering graduates, although their share declined steadily from over 75 percent in 1989 to under 65 percent in 2013. At the bachelor's degree level, international students comprise a steady 6 to 8 percent share of engineer degrees awarded. The decline in the white non-Hispanic share was counterbalanced by growth in domestic Asian and Hispanic students, and

25. All data are from authors' calculations from the 2008 SESTAT.

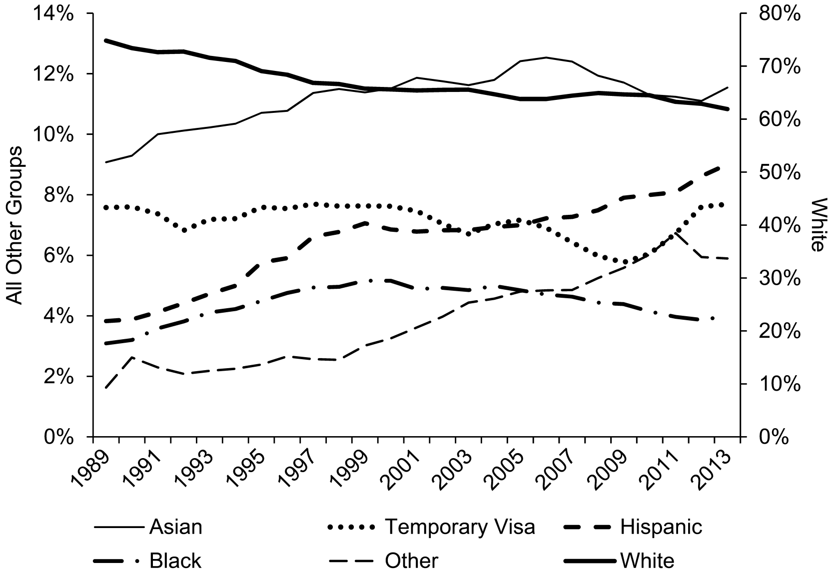

Fig. 1.7 Race and ethnicity composition of engineering bachelor's degree awards, 1989–2013

Source: Authors' calculations from engineering degrees in the IPEDS, 1989–2013.

students of other races or ethnicities. In 2013, African American students made up the smallest share of engineering graduates out of all the groups represented in figure 1.6, comprising between 4 and 5 percent over the past two decades. The largest nonwhite share of bachelor's degrees are held by Asians, at 9 to 12 percent, with small but steady increases by Hispanics, rising from 4 to 9 percent since 1989.

Although engineering has the lowest percentage of women of all STEM fields, with less than one-fifth of all engineering bachelor's degrees going to women, there is quite a large variation by engineering field. Table 1.8 provides the female share of bachelor's awards in the same selected subfields graphed in figures 1.2 and 1.4, as well as three other subfields of particular interest due to their very high or very low female shares. The two largest fields, electrical and mechanical engineering, both have relatively low female shares of just under 12 percent. In civil engineering and "other" engineering categories, women obtain one-fifth to one-quarter of degrees awarded. However, the share of "other" engineering awards going to women obscures broad variation across subfields in this category. Computer engineering, for example, has very low female representation at under 10 percent. In contrast, biomedical and environmental engineering have the highest female representation of all engineering, at 39 and 45 percent, respectively.

The share of foreign students (those on F-1 student visas) in engineering

Table 1.8 **Female share of engineering fields**

Engineering field	Female share of bachelor's awards (%)
Electrical	11.76
Mechanical	11.99
Civil	21.44
Other	24.11
Biomedical	38.93
Computer	9.91
Environmental	45.05
Chemical	32.27
Industrial	29.77
Aerospace	13.72
Materials	29.76
Total	19.36

Source: Authors' calculations from the 2013 IPEDS.

varies dramatically between undergraduate and graduate degree awards. At the undergraduate level, foreign students have comprised just under 10 percent of all engineering bachelor's degrees for over two decades. At the master's and doctoral levels, however, the share has increased from under 30 percent to over 40 percent at the master's level, and from just under 50 percent to around 60 percent in recent years at the doctoral level. The number of degrees at each level varies (see figure 1.8); in 2013, foreign students received about 7,000 bachelor's degrees, just under 18,000 master's degrees, and about 2,400 PhDs. The large number of master's degrees awarded to foreign students reflects, in part, the migration of students who receive a bachelor's degree in their home country and then enter a U.S. master's degree program both to obtain an engineering degree that may better qualify them for employment and also as the "entry portal" into the U.S. labor market. For most U.S. students, the bachelor's degree is the terminal degree and sufficient for entry into the engineering labor market.

1.4 Conclusion

Engineers are fundamental to a well-functioning, developed economy. The generation and maintenance of modern technology and the infrastructure that supports the nation would be unthinkable without engineers, who operate as the intermediary between scientific advances and improvements in everyday life. As such, researchers and policymakers are justifiably interested in the functioning of the labor market for engineers, and particularly whether the transition from school to work for new engineers is operating smoothly and providing a reliable supply to industry and government.

This chapter provides an overview of these issues. The first section con-

Fig. 1.8 Share of foreign engineering graduate student (F-1) visas, 1989–2013
Source: Authors' calculations from engineering degrees in the IPEDS, 1989–2013.

sidered some major factors in the demand for engineers, which varies widely by field and industry. Some fields, such as civil and electrical engineering, are in demand across a wide range of industries, while others such as chemical engineering are concentrated in a single industry, in many cases the manufacturing sector. This differential distribution of engineers across industries has important consequences for the response of the engineering labor market to vicissitudes of the business cycle. Over the last thirty years an increasing share of engineers have been employed in independent engineering firms, reflecting broader trends of outsourcing in the economy.

While most engineers are employed in the private sector, government is an important force in the labor market for certain types of engineers. Many civil and environmental engineers, for example, are employed in infrastructure projects that are publicly funded. Alternatively, specialized engineering fields like aerospace and biomedical engineering are often heavily dependent on federal grants and contracts, if not the beneficiaries of direct federal employment. Finally, the replacement of aging workforces does not appear to be a critical factor in the overall demand for engineers. Aging workforces are generally workforces that are in decline, and employment growth for younger workers tends to be in growing industries rather than for replacement. While replacement of retiring workers is always occurring, aging workforces are typically not a sign of impending replacement demand as the source of increasing demand for new graduates.

The next section considered the production of new engineers by colleges and universities. The pattern of engineering bachelor's degree awards varied substantially across fields. Civil and mechanical degrees, for example, exhibited a strong cyclicality that reflected the business cycle, electrical engineering showed much more dramatic shifts over time—most notably, a steep decline in the production of electrical engineering students in the 1980s—that were closely correlated with declining labor market opportunities for electrical engineers but did not reflect the overall business cycle. A few smaller fields, like computer and biomedical engineering, showed consistent secular growth at the undergraduate level. In contrast with bachelor's degrees, graduate degree awards showed persistent gains over the last thirty years.

In the midst of often heated policy debates about engineering labor shortages it is useful to take a step back and explore the functioning of the engineering labor market piece by piece: the demand for engineers, the supply of new engineers, and the institutional environment that produces new engineers. Not surprisingly each of these pieces of the labor market has exhibited both consistency and change over the last thirty years, and a steady eye on each of them is required for a clear understanding of the experiences of American engineers going forward.

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