The Labor Market for New Engineers: An Overview of Recent Trends[1]

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1.1 Introduction

The engineering workforce is small but vital to the functioning of the economy, the U.S. military, and the strength of the country as a global innovation leader. Maintaining the engineering workforce and adequate new infusions of trained engineers is thus considered to be an issue of concern of public policy beyond more general workforce development needs[2]. Markets for labor with specialized skills, including the market for engineers, operate differently from more generalized labor markets in many respects. They may be slower in adjusting to immediate changes in demand because of the formal and on-the-job training time necessary to acquire the requisite skills. Workers trained for specialized fields are also less substitutable with other types of workers. The result is that the short-run supply of engineers is relatively inelastic and shifts in demand are borne first by wage adjustments, and then by quantity adjustments (Hicks 1959; Freeman 1975, 1976; Ryoo and Rosen, 2004).

The inelasticity of the short-run supply of engineers and other skilled workers has generated a perennial interest in the potential for shortages in this critical workforce. Since at least the New Deal, when the rapid implementation of public investments raised the problem of bottlenecks in professional and scientific labor inputs (Allen and Thomas 1939), there has been a steady ebb and flow of concerns that the American economy confronted a shortage of engineers. Mobilization for the Second World War exacerbated these worries. After the war, discussion of a shortage of engineers briefly gave way to discussions of surpluses until the Korean War, when the fears reemerged. Anxiety about a shortage of American engineers reached a crescendo in 1957, when the Soviet Union launched Sputnik, the first man-made satellite to orbit the Earth. In response to the perceived crisis, a series of economic studies by economists emerged by the late 1950s to examine the extent of the engineering "shortage". Blank and Stigler's *The Demand and Supply of Scientific Personnel* (1957) emphatically concluded that there was no shortage of engineering labor, a finding with which Hansen (1961) concurred. Blank and Stigler (1957) and Hansen (1961) contended that previous claims of engineering shortages had failed to acknowledge the traditional labor market mechanisms that would guarantee equilibrium. These studies allowed for the possibility that the supply of engineers may fall short of some broader social purpose, such as beating the Soviets into space, but that there was no indication that the engineering labor market was malfunctioning.

Labor shortage fears have persisted into the twenty-first century, perhaps most notably in the National Academy of Sciences' book "Rising Above the Gathering Storm," with the title storm referring to the prospect of America being surpassed as a source of scientific breakthroughs and technological innovation. It therefore remains important to investigate the workings of the engineering labor market not just as a matter of academic interest, but also as a means of informing public policy. This chapter provides background information on trends in the supply of new engineers to the labor market over the last three decades in order to inform the policy debate. Section 1.2 identifies forces shaping the demand for engineers over the last three

[1] We are grateful for insights provided by Ron Hira, Sheri Shepard, Robert Lerman, Richard Freeman, Urban Institute seminar participants.

[2] See, for example, the National Academy of Engineering's "Engineering Research and America's Future: Meeting the Challenges of a Global Economy" (2005).

decades, including changes in the demand for engineers across industries, fluctuations in government demand, the demand for engineers in non-engineering occupations (particularly management), and replacement demand. This discussion of the current demand for engineers provides a context for interpreting trends in the supply of new engineers from American colleges and universities, which are presented in section 1.3. This section considers trends in undergraduate and graduate degrees separately. Section 1.4 concludes with a discussion of the nature of adjustments in the production of new engineers to changing demand conditions.

The labor market for engineers may function differently from other labor markets for several reasons: engineering education requires intensive and highly prescribed curriculum and therefore supply may be slow in responding to demand; there is limited transferability of skills between many of the engineering fields and even less substitutability with other segments of the workforce, limiting the potential for adjustments in the existing engineering workforce the eligible poo of college students may be limited to the extent of strong science and math secondary education[3]. In globalized labor markets, the response of domestic labor supply to changes in demand will also be muted as employers respond to tightening engineering labor markets by shifting work offshore. The pressure valve of international competition is considered to be an important source of flexibility for some people and a dangerous opportunity for deskilling and wage repression by others. All of these features of the market for engineers imply that shifts in demand will generally lead market adjustments, with lagged long-run supply responses. Short-run supply is therefore inelastic (Goolsbee 1998; Romer 2001; Bardhan, Hicks, and Jaffee 2012), so that most shifts in demand are borne by adjustments to wages in the short run, and employment levels in the long run.

We begin 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 to provide a context for a subsequent discussion of shifts in the supply of new engineers. The data used in this section come from the National Science Foundation's (NSF) semi-annual Scientists and Engineers Statistical Data System (SESTAT). The SESTAT dataset combines three NSF surveys, the National Survey of College Graduates (NSCG), the National Survey of Recent College Graduates (NSRCG), and Survey of Doctoral Recipients (SDR) to construct a nationally representative sample of college degree holders. This chapter focuses on the subset of degree holders in the SESTAT data who earned at least one degree in an engineering field[4].

1.2 The engineering workforce

The common thread of the Bureau of Labor Statistics engineering occupation definitions is a worker that designs, develops, and tests solutions to technical and physical problems faced by industry and government. Although popular analyses and policy makers typically refer to engineers as a single group, with the assumption that this represents a more or less homogenous workforce and labor market, it is a remarkably heterogeneous workforce in terms of education, skills, industry representation, and role in the economy. Civil engineers, for example, are

[3] This argument is summarized and addressed by Lowell and Salzman (2007).

[4] References to graduates in the SESTAT data working in engineering occupations exclude "software engineers," who primarily do programming tasks rather than engineering tasks. Computer hardware engineers are considered to be employed in "engineering occupations".

primarily involved in construction work and are primarily employed in independent engineering firms. In contrast aerospace engineers are seldom self-employed or employed by engineering firms, working instead in for very large aerospace 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. Manufacturing engineers will be affected by the business cycle, but they are sensitive to the decisions of individual firms about the global location of manufacturing operations in a way that civil engineers would not be. Engineers involved in research and development, those generally identified as crucial to American innovation and growth, are a small portion of the engineering workforce, 16.5 percent, though that probably underrepresents the number of engineers involved in core research and development activities as part of their job but reported in another classification (National Science Foundation, 2012, table 3-12).

Engineers in different fields are employed in quite different industries, and their employment patterns change over time as the American economy itself changes. A summary of the changes to the distribution of engineers across industries over the last thirty years is provided in tables 1.a. and 1.b., which presents the share of engineers employed in major industry categories in 1980 and 2010 for each detailed engineering occupation. Some occupations, like computer engineers and environmental engineers, were not even recorded as a separate field in 1980. Presumably the few engineers doing comparable work in 1980 were categorized as electrical engineers (computer), or civil engineers (environmental).

Table 1.a. Engineering occupation distribution across industry

	Aerospace		Biomedical & agricultural		Chemical		Civil		Computer		Electrical		Environmental		Industrial	
Industry	1980	2010	1980	2010	1980	2010	1980	2010	1980	2010	1980	2010	1980	2010	1980	2010
Agriculture and Forestry	0.0	0.0	2.1	0.4	0.0	0.0	1.1	0.4	--	0.0	0.0	0.0	--	0.1	0.1	0.1
Mining and Extraction	0.1	0.0	0.0	0.0	1.6	0.6	0.6	0.1	--	0.1	0.4	0.5	--	1.8	0.9	0.6
Construction	0.1	0.0	0.8	0.0	2.0	0.9	39.8	23.5	--	0.4	2.3	2.2	--	1.4	2.1	0.9
Manufacturing	88.1	85.7	53.4	54.0	80.5	89.7	6.3	1.7	--	32.3	50.4	44.9	--	13.2	79.9	76.3
Retail and Wholesale	0.1	0.3	0.8	1.3	1.8	0.7	0.5	0.3	--	4.4	1.3	2.3	--	1.1	1.4	1.6
Transportation and Utilities	1.9	2.2	0.0	0.0	1.8	1.0	8.9	4.2	--	1.0	11.6	11.7	--	14.9	3.7	2.3
Information	0.2	0.1	0.8	0.0	0.0	0.0	0.6	0.3	--	4.6	15.9	10.7	--	0.0	0.6	1.4
Finance, insurance, and real estate	0.0	0.2	0.4	0.0	0.2	0.0	1.0	0.3	--	8.9	0.2	0.6	--	0.0	2.4	1.2
Professional, Scientific, and Technical Services	4.1	7.0	3.4	12.5	8.9	5.8	23.8	59.9	--	37.1	10.6	20.6	--	43.3	3.5	11.5
Education, Health, Arts, Entertainment, and Other Services	0.2	0.8	24.4	28.5	0.9	0.5	1.2	1.0	--	7.1	2.1	2.3	--	4.9	1.4	1.7
Public administration	5.1	3.8	13.9	3.3	2.4	0.8	16.2	8.3	--	4.0	5.2	4.4	--	19.3	4.2	2.4

Source: Authors' calculations from the IPUMS 5 percent microdata sample of the 1980 Census for the 1980 figures, and the 2010 American Community Survey for the 2010 figures.

Table 1.b. Engineering occupation distribution across industry, continued

	Marine		Materials		Mechanical		Mining & petroleum		All other engineers		Engineering technicians		Total Percent		Total (Thousands)	
Industry	1980	2010	1980	2010	1980	2010	1980	2010	1980	2010	1980	2010	1980	2010	1980	2010
Agriculture and Forestry	1.5	0.8	0.0	0.0	0.1	0.0	0.3	0.2	0.2	0.0	0.4	0.3	0.3	0.1	6.5	3.2
Mining and Extraction	1.8	1.1	2.0	0.2	0.6	0.9	79.8	71.9	0.7	0.2	1.3	1.6	2.2	1.7	47.2	41.9
Construction	1.0	0.8	1.9	0.2	2.8	2.2	0.9	0.3	1.5	0.4	9.3	3.9	8.1	4.7	171.2	115.9
Manufacturing	21.4	47.5	78.4	89.8	75.9	72.6	5.7	9.5	37.2	30.5	46.6	42.0	50.4	44.0	1,071.7	1,077.4
Retail and Wholesale	0.6	2.2	1.2	0.2	1.7	2.0	2.4	4.6	3.9	1.5	2.6	2.9	2.0	1.8	41.3	43.4
Transportation and Utilities	57.5	20.0	2.0	1.0	3.7	2.4	2.0	3.8	5.1	8.2	6.1	7.4	6.7	5.9	142.3	144.5
Information	0.0	0.0	0.2	0.0	0.3	0.2	0.1	0.0	1.3	4.7	2.7	9.7	3.7	4.3	78.6	106.2
Finance, insurance, and real estate	0.4	0.6	0.0	0.0	0.5	0.4	0.3	0.3	0.5	0.9	0.6	0.7	0.7	0.8	13.9	19.9
Professional, Scientific, and Technical Services	9.0	14.5	7.1	5.0	9.8	13.9	5.4	7.9	35.2	35.6	12.0	13.3	14.2	25.1	301.8	614.7
Education, Health, Arts, Entertainment, and Other Services	1.6	0.7	3.3	0.9	1.5	3.4	0.4	0.2	3.0	3.2	9.5	10.2	4.1	4.1	87.2	99.9
Public administration	5.3	12.0	3.9	2.9	3.3	2.2	2.8	1.4	11.5	14.9	8.9	8.1	7.8	7.4	165.9	180.7

Source: Authors' calculations from the IPUMS 5 percent microdata sample of the 1980 Census for the 1980 figures, and the 2010 American Community Survey for the 2010 figures.

Engineers are concentrated in the manufacturing sector, with 50.4 percent working in that industry in 1980 and 44 percent (a plurality) in 2010. Many engineering occupations are even more heavily concentrated in manufacturing and have remained so over the last thirty years, including aerospace, chemical, industrial, marine[5], and materials engineers, in addition to engineering technicians. Biomedical and agricultural engineers have also been primarily employed in manufacturing, although a sizeable share of this field (roughly a quarter) is also employed in the health sector. The manufacturing sector shed well over a quarter of its workforce between 1980 and 2010 (with most of the decline coming after 2000), due to a combination of productivity improvements, offshoring, and foreign competition (CBO, 2008). Despite this substantial decline in the total manufacturing workforce, the total number of engineers employed in manufacturing increased modestly between 1980 and 2010. This is consistent with theories of skills biased technological change, which attribute increasing inequality to technological change that affords employment opportunities to high skill workers and lower skill service workers, but automates many middle skill jobs (Card and DiNardo, 2002). Brown and Campbell (2001) specifically consider the prospects of engineers through a period of technological change in semiconductor fabrication plants. They find that demand for engineers in innovating semi-conductor fabrication firms increased relative to non-innovating firms.

The occupations that have exhibited the most substantial change in their distribution across industries have been those that migrate into the professional, scientific, and technical services industry due to the outsourcing of engineering tasks to dedicated engineering firms. In 1980, 14.2 percent of engineers worked in this industry, increasing to 25.1 percent by 2010. The most substantial entrants into the professional, scientific, and technical services industry have been civil and electrical engineers, two of the largest engineering occupations. Electrical engineers primarily left the manufacturing sector, while civil engineers migrated out of construction and public administration.

Engineering graduates working as engineers are paid well. Table 2 presents the real (2012 dollar) salaries for four major categories of engineers and for all other engineers in selected years between 1993 and 2008. Chemical and electrical engineers are paid particularly well, with civil engineers regularly receiving lower salaries. Between 1993 and 2008, electrical engineers saw much stronger salary growth than their counter-parts (20.3 percent), with mechanical engineers enjoying strong growth as well (14.1 percent). In the case of electrical engineers, this marks the reversal of a weakening of labor market conditions and better alternative opportunities that occurred in the mid-1980s, driving many students out of electrical engineering programs. This decline in electrical engineering prospects is discussed in more detail in section 1.3, below. Engineer salary trajectories are traditionally relatively flat

Table 2: Engineering graduate real (2012 dollar) salaries, by occupation

	Chemical	Civil	Electrical	Mechanical	Other
1993	$90,564	$76,265	$84,209	$79,442	$81,031
1995	$90,389	$75,324	$84,363	$78,337	$79,844

[5] Table 1.b. seems to suggest that large share of marine engineers migrated from the transportation to the manufacturing sector over the last several years. This is, in fact, an artifact of changes in industrial classifications. The use of broad sectors for tables 1.a. and 1.b. generally guarantee that the industries are comparable across years. However, the classification of a large number of marine engineers was affected by the decision to change ship building and repair that occurred in drydocks from a manufacturing industry to a transportation industry. Ship building that does not occur in drydocks is consistently classified as a manufacturing industry.

1997	$92,980	$74,384	$88,688	$81,536	$85,828
1999	$96,466	$79,929	$96,466	$85,441	$88,197
2003	$96,078	$83,600	$99,821	$89,839	$93,582
2006	$96,801	$81,996	$97,940	$88,829	$91,107
2008	$100,239	$85,309	$101,305	$90,641	$93,840
% Change, 1993 to 2008	10.68%	11.86%	20.30%	14.10%	15.81%

Source: Authors' calculations from SESTAT 1993-2006. The sample is restricted to employed respondents who earned a bachelor's degree or higher in engineering, and is weighted to be nationally representative.

Standard occupational categories and well defined professional demarcations make identifying a given worker as an "engineer" relatively straightforward. However, discussions of the supply and demand for engineers raise more difficult questions about who is and is not in the engineering labor market. For example, in 2008 only 43 percent of engineering degree holders were working as engineers. Although the remaining 57 percent of engineering degree holders were not working as engineers at the time, they were potentially available to supply their labor to that market if salaries reached a sufficient level. In contrast, other individuals working as engineers (usually between a fifth and a quarter of the total) have no degree in engineering at all. Although they are classified as engineers their labor and the tasks they perform may be less interchangeable with degree holders. Since the second half of this chapter is focused on the supply of new engineering graduates, the subsequent background sections on the engineering workforce will take engineering degree holders as the relevant universe. While these figures may differ in certain ways from other estimates, they should be largely comparable and they are the most appropriate population for discussing the market conditions awaiting new engineering graduates.[6]

1.2.1 Engineers as managers

One of the challenges associated with assessing arguments about shortages of engineers is identifying exactly who is demanding engineering labor. While many trained engineers work in a designated "engineering" occupation, their education is considered valuable in a variety of settings, including the management of technical operations, which benefits from the systems thinking taught to engineers. This confluence of skills demanded by a variety of employers introduces an occupational self-selection problem, the solution of which may not always result in trained engineers working in an engineering position. Workers with multiple skills will self-select into occupations where they expect the highest returns, potentially working in an occupation where they have lower absolute, but higher comparative, advantage. When technical and managerial skills are likely to be positively correlated and demand for managerial skill is high, trained engineers with the highest technical and managerial skills may self-select into management occupations (Biddle and Roberts 1994).

The career trajectory of engineers from technical to managerial positions has been a long-discussed issue. Historically, mobility into management was viewed as a consequence of quickly plateauing salaries for engineering positions (compared to other professions) and the need for managers to have technical expertise in firms that focused on product innovation and

[6] Ambiguous definitions plague analysis of the science and engineering workforce in general, not simply the engineering workforce. See figures 3-10 and 3-11 in the National Science Foundation's 2012 *Science and Engineering Indicators* for an example of the multiple definitions of the "science and engineering workforce" made possible by the dual occupational and educational identity of this class of workers.

development as their primary competitive strategy. In the post-war period, various management professions expanded (from operations management to logistics, to finance) and began to play a more central role in corporate strategy. This post-war rationalization of management is perhaps best exemplified by Robert McNamara's transition from his role as one of the World War II "whiz kids", using mathematical models to manage wartime logistics, to his successful leadership of Ford Motor Company. During the 1970s, with the incursion of Japanese automobiles into the U.S. market, their engineering superiority was credited, in part, to having those companies led by engineers rather than managers with finance, marketing, and management degrees. It was during this period that firms began to develop highly paid technical tracks as a way to retain experienced engineers in technology and development positions. Nonetheless, the salary premium for engineers moving into management positions increased steadily from the early 1990s through the mid-2000s.

Observed median salaries of engineering graduates working as engineers are consistently lower than median salaries for engineering graduates working as managers (Table 3). To a large extent, this is due to the fact that engineers move into management positions as they get older, bringing higher levels of human capital to the wage bargain. Table 3 also presents median wage differentials that control for the compositional differences between managers and engineers, including differences in age and in field of study. Although the wage premium enjoyed by manages is reduced by this exercise, most of the differential remains. Between 1993 and 2006, the ratio of the median salaries of engineering graduates working as managers to those working as engineers increased steadily, even after controlling for compositional differences, suggesting an increased demand for managers pulling skilled engineering graduates out of engineering occupations. In 2008 this trend reversed, and the management premium for engineering graduates began to decline. Although this may be related to the Great Recession, it is likely that more fundamental forces are underlying the reversal since most of the impact of the recession on the real economy arrived in 2009, and both engineers and managers would have been affected by that shock. The next wave of the SESTAT survey will provide additional insights into whether this moderation of the upward trend in the wage premium enjoyed by managers will continue.

Table 3: Median real (2012 dollars) salary by occupation of engineering graduates

	Median salary of engineers	Median salary of managers	Ratio	Ratio controlling for age	Ratio controlling for age and field of study
1993	$81,031	$114,397	1.41	1.30	1.29
1995	$79,844	$114,493	1.43	1.33	1.33
1997	$85,828	$120,159	1.40	1.36	1.37
1999	$89,575	$130,918	1.46	1.41	1.36
2003	$93,582	$143,493	1.53	1.49	1.48
2006	$91,107	$142,354	1.56	1.52	1.53
2008	$92,774	$138,628	1.49	1.46	1.45

Source: Authors' calculations from SESTAT 1993-2006. The sample is restricted to employed respondents who earned a bachelor's degree or higher in engineering, and is weighted to be nationally representative.

Despite growing manager wage premiums from 1993 to 2006, the share of engineering graduates who reported working as managers declined over this period by 9 percentage points, from 17.2 to 8.9 percent (Column 3, Table 4). Similarly, the share of engineering graduates working in the more specialized occupational field of "engineering manager" declined from 8.4 percent in 1993 to 5.57 percent in 2008. As the likelihood of an engineering graduate working as

a manager decreased over this period (columns 3 and 4 of Table 4), the share of engineers who have managerial responsibilities in addition to their technical responsibilities increased (column 1 of Table 4). Firms employing engineers appear to be flattening their occupational hierarchies by combining technical and management responsibilities, even as compensation policies incentivize engineering graduates to move into management.

Table 4: Management and engineering graduates

	(1)	(2)	(3)	(4)
	Engineering graduates working as engineers	Share of column (1) with management responsibilities	Engineering graduates working as managers	Engineering graduates working as "engineering managers"
1993	49.10%	46.31%	17.24%	8.37%
1995	49.45%	49.64%	17.07%	7.72%
1997	49.72%	50.89%	14.90%	6.58%
1999	49.23%	54.24%	13.12%	5.91%
2003	42.39%	55.68%	7.50%	3.84%
2006	44.00%	57.29%	8.20%	3.95%
2008	42.86%	58.67%	8.89%	5.57%

Source: Authors' calculations from SESTAT 1993-2008. The sample is restricted to employed respondents who earned a bachelor's degree or higher in engineering, and is weighted to be nationally representative.
Note: Engineering managers are not included as an occupational category in the SESTAT surveys before 2003. Engineering managers before 2003 are defined as managers with an engineering degree who reported that their job was "closely related" to their degree, following the strategy used by Burton and Parker (1998).

These findings are consistent with observed trends in corporate and occupational structure. In the 1990s corporate restructuring eliminated layers of middle management, some firms expanded the decision making authority of professionals and minimize bureaucracy and hierarchy to reduce labor costs. The managerial skills needed were organizational, communication, and other "boundary spanning" skills that reflected the cross-disciplinary, cross-organizational nature of technology projects Salzman and Lynn (2010). They note that the increasing overlap between product development, engineering, and marketing activities in manufacturing firms requires employees that were exclusively dedicated to certain stages of production to interact more regularly with each other, requiring a capacity for management and communication on the part of all workers, including engineers. Interviews with engineering managers in a study by Lynn and Salzman (2002) found that hiring engineers with technical skills was not considered to be a problem; rather, it was workers with "soft skills" such as communication and management that were harder to recruit. This trend in demand for a broad skill set and an occupational structure with less rigid task boundaries was also found to be characteristic of the Japanese engineering profession (Lynn, Piehler, and Kieler, 1993; Lynn, 2002), and a reversal of the increasingly hierarchical organization of the engineering occupation during the 1960s and 1970s (Ferrall 1995). Hill (2007) suggests that universities have begun to respond to this demand for "multidimensional" engineers through cross-disciplinary initiatives and course offerings, and LeBold, Burton, and Parker (1998) highlight substantial on-the-job training in management skills.

At the same time, during this period firms deemphasized innovation-led strategies and focused more on financial strategies, what some refer to as the "financialization" of firms (Lazonick, 2009). Beginning in the early 2000s, firms began to offshore engineering and other technical work (Lynn and Salzman 2010; Salzman and Biswas 2000), further reducing labor costs and the technical component of work activities within the U.S.. Our findings are consistent

with these changes, the declining role of engineering work in firm strategy, and of the centrality of non-engineering management.

Consideration of the choice between technical and managerial jobs faced by employers and engineering graduates necessarily raises the issue of replacement demand for engineers. Engineers who move into management are typically older, and since they are unlikely to switch back to a technical track after moving into management (Biddle and Roberts 1994) they must be replaced by an infusion of new engineering graduates if demand for engineers is maintained. The significance of replacement demand as a source of demand for new graduates is discussed in the next section.

1.2.2 Government employment of engineers

Government is one of the largest employers of engineers, both directly as public employees and indirectly in private companies working on government contracts. Many notable cases of sharp increases in the public demand for engineering labor, from the interstate highway system to the Reagan military buildup have had a dramatic impact on the labor market and supply. In the post-WWII period, as the federal government re-oriented itself to its new role as a permanent supplier of public infrastructure, research and development, maintaining a large standing military and expanding the role of science and engineering in defense strategy, from weapons development to espionage.

As a major employer of engineers (and scientists), the federal policy makers focused on programs that could develop this workforce and forecast future demand rather than relying on markets that would be subject to feared lags or shortages. In doing so, federal policy makers 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). The tone of federal manpower planning was set by Vannevar Bush in his 1945 report *Science, the Endless Frontier*, which set out the vision for post-war government science policy. Bush's discussions of the science and engineering workforce were not alarmist and were essentially corrective: he advised the production of new scientists and engineers to make up for the young men that went to war instead of going on to college. 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). While federal assessments of the engineering workforce can be susceptible to unwarranted concerns about labor shortages[7], the economics literature furnishing evidence against shortage concerns did have an impact on government characterizations of the market for engineers. In 1986 a report by the National Academy of Engineering on the impact of increased Reagan-era

[7] 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, p. 1). A recent example is the National Academies' (2007) *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" (p. 3).

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).

Engineers are attracted to government employment or contract work for a variety of reasons. Schott (1978) highlighted the priority of job security for engineers seeking government jobs. This security is of course also extended to private sector positions supported by reliable government contracts. Thomas and Ong (2002) and Gibbs (2006) emphasize the highly specialized nature of the work performed by public sector (or government contractor) engineers relative to the engineers working in and for the private sector. This opportunity for specialization on a high-technology project may be an attraction for job seekers. However, Thomas and Ong (2002) also find that specialization was a liability for aerospace engineers struggling with defense budget cuts. With declining federal contract opportunities at the end of the Cold War, aerospace engineers were left to compete for work out of their direct field of expertise and in firms with quite different organizational cultures. In an investigation of the reemployment prospect of these engineers, Thomas and Ong (2002) learned that highly specialized experience, along with acclimation to the government's large bureaucratic culture, which privileged quality over quantity, made the transition from the public to the private sector challenging. Private sector firms seeking engineers noted that aerospace engineers formerly working for the government were unable to adjust to the smaller, nimbler, more quantity-oriented work available outside of government.

Aerospace engineers are the quintessential example of federal employees or privately employed federal contractors with relatively specialized engineering skills. The federal government is the primary government employer for development of military technology and systems, of biomedical and other research, and large infrastructure projects and programs that rely on extensive computer networks. 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 responsibilities. The skill sets of these engineers are generally more homogenous, and they are used to working in smaller firms than the larger firms working on federal contracts. Table 2, below, presents the composition of the public sector engineering workforce in 2010[8].

The example of federally employed aerospace engineers provided above makes up less than ten percent of the engineers directly employed by the federal government. The plurality (26.3 percent) of federally employed engineers has no specialized field identified at all. A large share are electrical and electronics engineers (4.4 and 18.4 percent, respectively), mechanical engineers (12.1 percent), and civil engineers (10.9 percent). The state and local engineering workforce is far less occupationally diverse. Over two thirds (68.6 percent) are civil engineers and much of the rest are environmental engineers (12.5 percent).

Table 2: Engineers directly employed by federal, state, and local governments in 2010

	Federal		State and Local	
Engineering Occupation	Number	Percent	Number	Percent

[8] Federal employment of engineers in the OES data from 2008 is of comparable magnitude to NSF estimates using data from the Office of Personnel Management (NSF 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 difference 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.

Aerospace engineers	9,220	9.52%	0	0.00%
Agricultural engineers	400	0.41%	0	0.00%
Biomedical engineers	500	0.52%	40	0.04%
Chemical engineers	1,130	1.17%	110	0.12%
Civil engineers	10,630	10.98%	61,030	68.64%
Computer hardware engineers	4,430	4.58%	120	0.13%
Electrical engineers	4,260	4.40%	3,130	3.52%
Electronics engineers, except computer	17,790	18.37%	540	0.61%
Engineers, all other	25,450	26.29%	6,570	7.39%
Environmental engineers	3,800	3.92%	11,120	12.51%
Health and safety engineers, except mining	710	0.73%	2,940	3.31%
Industrial engineers	1,340	1.38%	510	0.57%
Marine engineers and naval architects	910	0.94%	70	0.08%
Materials engineers	1,320	1.36%	300	0.34%
Mechanical engineers	11,710	12.09%	1,950	2.19%
Mining and geological engineers	160	0.17%	410	0.46%
Nuclear engineers	2,730	2.82%	70	0.08%
Petroleum engineers	330	0.34%	0	0.00%
Total	96,820		88,910	

Source: Authors' calculations from the 2010 OES. "Engineers, all other" includes non-listed engineers or potentially engineers with no designated occupational field.

Federal engineering employment was lower in the early 2000s (between 82,000 and 87,000 from 2000 to 2005) than it was in the immediate aftermath of the Cold War (1998-2003), when the federal government employed between 95,000 and 98,000 engineers. However, by the end of the 1990s engineers directly employed by the federal government increased back to their immediate post-Cold War levels, at 96,820.[9] The percent of all engineering graduates working in an engineering occupation who are either employed by the government or who are working on a government contract has remained relatively steady during the post-Cold War period, ranging from around 35 to 37 percent of the total (Table 3), with most of those engineers working on government contracts rather than directly for the government[10]. These contractors are not necessarily exclusively doing government work; they may also have private contracts. The share of engineering graduates working as engineers working for the government work as contractors (rather than as direct employees), has increased steadily over time from just under 60 percent in 1993 to just over 70 percent in 2008.

Table X: Engineering graduates working as engineers and government

	(1)	(2)	(3)	(4)
	Percent employed by the government or as government contractors	Number employed by the government or as government contractors	Contractor share of government engineers (share of column 1)	Number employed as government contractors
1993	37.50%	396,051	59.64%	236,210
1995	36.66%	396,517	62.47%	247,718
1997	34.61%	388,074	63.15%	245,075

[9] See the National Science Foundation's 2008, 2005, and 1995 reports on Federal Scientists and Engineers.
[10] The total government employment of engineers reported in Table 3 below is somewhat smaller than what is reported in Table 2, above, because Table 2 is restricted to college degree holders with a degree in engineering. Some workers classified as engineers only have associates degrees, or they have degrees in non-engineering fields.

1999	--	--	--	--
2003	35.50%	430,473	67.66%	290,974
2006	36.15%	477,088	69.35%	330,782
2008	36.47%	477,306	70.12%	333,859

Source: Authors' calculations from SESTAT 1993-2008. The sample is restricted to employed respondents who earned a bachelor's degree or higher in engineering, and is weighted to be nationally representative. The 1999 SESTAT is excluded because it does not whether respondents are government contractors.

The government is likely to continue to play an important role in the demand for engineers, particularly in specialized occupations like aerospace (through defense contracts) and nuclear engineering (directly through defense contracts and indirectly through regulation, new reactor permits). Recent substantial increases in funding for NIH will be an importance force in shaping the demand for biomedical engineers inside and outside of government. This trend has already been bolstered by the emergence of a strong American comparative advantage in the life sciences. The veracity of demand for civil and environmental engineers by state and local governments is likely to be highly contingent on their fiscal positions, which have been battered by the Great Recession. Reduced tax revenues and balanced budget requirements make infrastructure investments (and derived demand for civil and environmental engineers) more challenging.

1.2.3 Retirement and replacement demand

One of the concerns about the engineering labor market concerns the impact of large attrition rates through retirement and older workers leaving the field. In aging engineering fields, replacement demand may be a major source of demand for new engineering graduates. A baseline rate of replacement demand is an inevitable reality in the engineering labor market. In addition to this baseline, the impending retirement of baby boomers has inspired fear that not enough graduates are being produced to replace retirees. Less strenuous observers note that even if the replacement of retirees is unproblematic, the problem of transferring knowledge from more experienced to less experienced engineers will be an important concern for the market (Gibson et al. 2003).

Freeman (2007) argues 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," and provides an empirical framework for investigating this issue, which is reproduced for engineering occupations in Table 5, below. Occupation-sector-education groups are constructed from SESTAT data, and serve as the unit of analysis in the regressions[11], which estimates the employment share of various age groups in 2008 on that specified group's employment share in 1997 and the share age 55 and older in 1997.

Table X: Estimated relationships between occupational employment of engineering graduates older than 55 in 1995 and employment of other age and immigrant groups in 2008

	Age Group in 2008	Foreign born in

[11] For example, one group 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 groups with less than twenty observations in the 2006 SESTAT sample were omitted from the analysis to ensure the reliability of the estimates of employment shares. Seventy-five occupation-sector-education groups were available in both 1995 and 2006. As with other analyses using the SESTAT data, the sample is restricted to holders of engineering degrees.

	20-25	25-35	35-45	45-55	2008
Share of workers age 55 and older, 1997	-0.389**	0.055	0.103	0.099	-0.291
	(0.151)	(0.124)	(0.130)	(0.152)	(0.225)
Share of workers in specified group, 1997	0.448**	0.424***	0.383***	0.125	0.725***
	(0.192)	(0.104)	(0.140)	(0.076)	(0.156)
Constant	0.136***	0.132***	0.151***	0.143***	0.201***
	(0.027)	(0.043)	(0.046)	(0.030)	(0.063)
R^2	0.362	0.222	0.151	0.047	0.364
Observations	78	78	78	78	78

Source: Authors' calculations from SESTAT 1997 and 2008. The sample is restricted to employed respondents who earned a bachelor's degree or higher in engineering, and is weighted to be nationally representative.

Occupations that are in steady state equilibrium, where new labor supply is sufficient for meeting replacement demand, would have employment shares for each age group in 2008 that are comparable to the employment shares of that age group in 1997. We would expect such steady state occupations to have significant coefficients for their specified age group, and no significant relationship between the employment share of engineers that are 55 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 55 or older in 1997 and the worker share of a younger age group in 2008.

The regressions provide no evidence that the share of younger workers (ages 20 to 25) increases in 2008 when a larger share of the occupation-sector-education group's workers are over the age of 55 in 1997, which might indicate a substantial role for replacement demand in the labor market faced by new engineering graduates. In fact, there is a negative relationship between these two variables, suggesting that older occupational groups in 1997 were not attracting younger workers through the late 1990s and early 2000s. Freeman (2007) interpreted a similar negative relationship in regressions for all occupations as evidence that older workers are concentrated in occupations with declining employment, where young are not hired to replace older workers. Hiring of younger workers instead goes on in growing occupations. Sources of engineering field decline may be the result of natural adjustments to the economy's structure, changes in government demand, and the offshoring of technical worker described in prior sections of this chapter.

The regressions show a positive, but statistically insignificant relationship between the share of workers older than 55 in 1997 and the share of workers aged 35 to 45 and 45 to 55 in 2008. This finding is also consistent with a declining occupation group. 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, as they themselves move towards retirement. 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 aging workforce that is growing rapidly and therefore drawing many new engineering graduates into the field with the incentive of higher salaries. Circumstances in the petroleum engineering industry are discussed in more detail by Salzman, Lynn, and Kuehn in Chapter XX.

An alternative explanation that is particularly relevant to the engineering workforce is that retiring engineers may be replaced by foreign born workers, rather than younger native workers. Matloff (2003) argues that foreign born workers are not simply a substitute for native

workers, but that they are actually a threat to relatively expensive older workers. This hypothesis is tested using the same regression framework Freeman (2007) uses to test the extent of replacement demand by age group. The share of foreign born workers in an occupation-sector-education group in 2008 is regressed on the share of foreign born workers in that group in 1997, and the share of workers age 55 and older in 1997. The foreign born share in 2008 is actually negatively related to the share of workers age 55 and older in 1997, although the relationship is statistically insignificant. This suggests that if the age profile of engineering fields has any relationship with hiring foreign born workers, it is probably a negative relationship. As with the case of younger engineers, aging engineering fields are declining engineering fields that do not attract new foreign workers. In 2008, immigrants were more likely to be employed in occupational groups where they were employed in 1997, but these regressions provide no evidence that immigrants are used as a strategy for adjusting the age profile of the engineering workforce, or to replace older native workers. Of course, this analysis does not invalidate the argument that firms are hiring immigrants to displace or replace older workers in non-engineering fields (for example, in information technology).

1.3 Engineering Education and the Supply of New Engineers

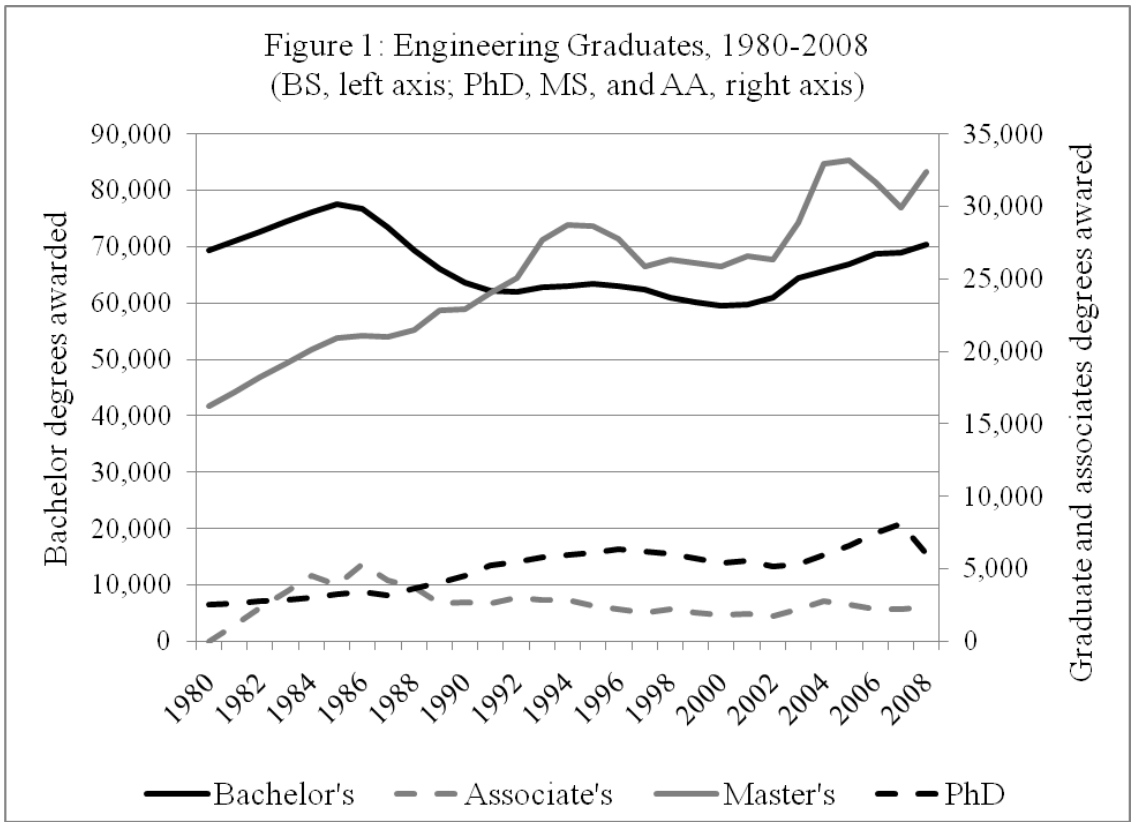
Engineers require specialized training, at least at the undergraduate and in many cases at the graduate level. As with most specialized professions, non-engineers cannot be easily substituted for engineers to meet demand. While former engineers can move back into the occupation from other occupations, this sort of labor "backtracking" is relatively rare (Biddle and Roberts 1993). 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 in this section using data from the Integrated Post-Secondary Education Data System (IPEDS), which collects detailed annual enrollment and graduation information on all post-secondary 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, which primarily produce software engineers and technicians, respectively, rather than engineers. IPEDS data is made publically available from 1980 to the present[12].

1.3.1 Bachelor's Degree Trends

Figure 1 presents data on engineering graduates from 1980 to 2008 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 80,000 degrees awarded every year during the thirty year period covered. Fewer graduate and associates degrees are awarded each year, so these degrees are measured according to the more compact scale on the right axis. No more than 35,000 master's degrees in engineering, and considerably fewer doctoral and associate's degrees have been produced annually since 1980.

[12] Data are unavailable between 1980 and 1984, or in 1999, and are linearly interpolated for these years. Engineering fields and programs in this section are identified using the IPEDS Classification of Instructional Programs, or CIP codes. These codes may not reflection organizational structure of the departments themselves in all cases.



Source: Authors' calculations from engineering degrees in the IPEDS, 1980-2008. Data are unavailable between 1980 and 1984, or in 1999, and are linearly interpolated for these years.

There are four distinct periods in the bachelor degree award trend in Figure 1. First, between 1980 and 1985, bachelor degrees in engineering increased from under 70,000 to just under 80,000. 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. This decline in bachelor's degrees in engineering after the peak in 1985 directly preceded several high profile expressions of concern over shortages of engineers, including Atkinson's (1990) article in *Science*, which anticipated "a major impact on economic growth, international competitiveness, and national security". 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 until the level of degrees awarded in 1980 (roughly 70,000 per year) was once again reached in 2008. Graduate degrees in engineering have experienced more consistent growth since 1980 than bachelor's degrees. Between 1980 and 2008, over a period where there were almost no net gains in bachelor's degrees awarded, the number of master's degrees in engineering awarded doubled from 16,000 to 32,000. Doctorates more than doubled from 2,500 to 6,000 over this period.

Each of these degree levels can be decomposed into more detailed engineering fields in which degrees are awarded. In this chapter, we consider trends in six engineering fields: electrical, mechanical, civil, chemical, computer, and biomedical engineering. The first four fields are the largest fields in which degrees are awarded, while computer and biomedical engineering are noteworthy for their strong recent growth. Together, engineering degrees in these

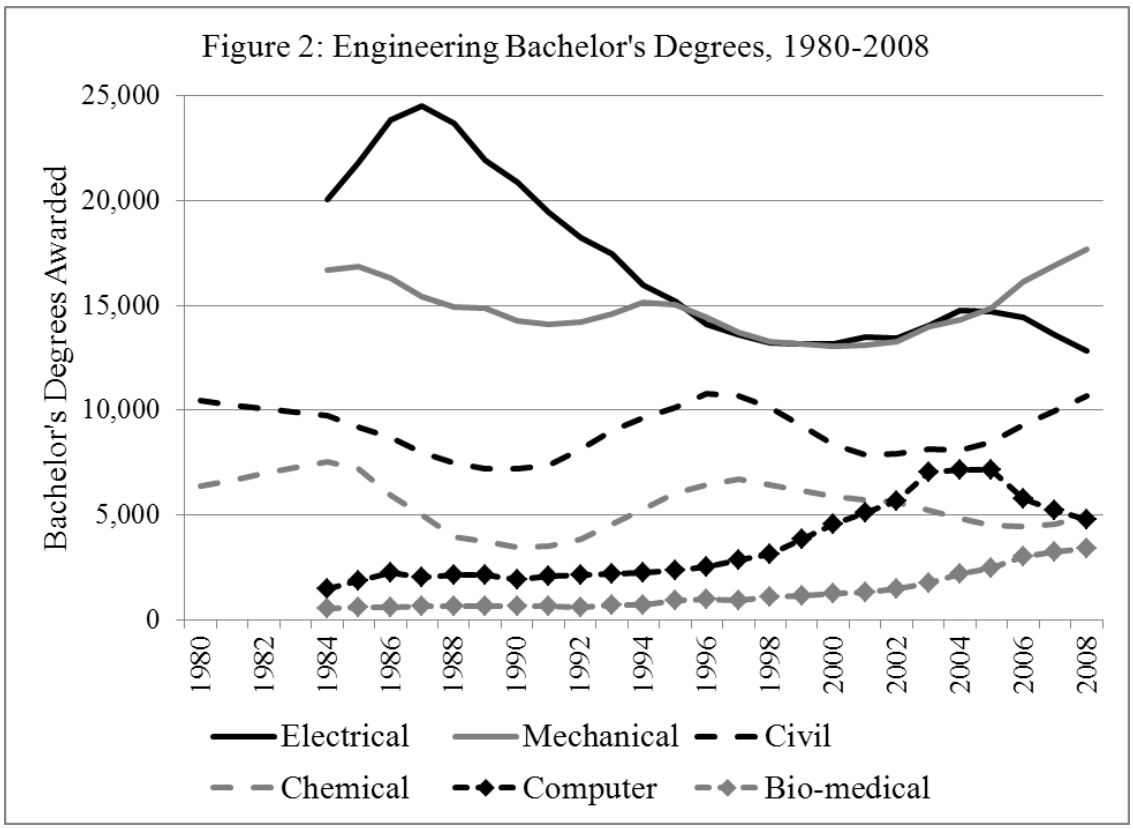
fields accounted for 77 percent of all engineering bachelor's degrees awarded in 2008. Trends in bachelor's degrees awarded in these six fields are presented in Figure 2. A major driver of the increase in engineering graduates in the mid-1980s was the high production of electrical engineering degrees, which made up a third of all engineering bachelor degrees in that decade. Data on bachelor's awards in electrical engineering are not available from the IPEDs data before 1984, but between 1984 and 1987 alone the number of electrical engineering bachelor's degrees awarded increased by over twenty two percent. Annual electrical engineering awards went into a period of sharp decline after 1987, dragging down total engineering awards during this period. Between 1987 and 1996, the number of electrical engineering bachelor's degrees awarded annually in the U.S. fell by over 10,000.

One possible explanation for this decline in electrical engineering awards is that starting in the late 1980s, undergraduates who may have been drawn to electrical engineering in previous years elected to major in a field that offered a close substitute, such as computer science. Between 1970 and 1980, bachelor's degrees in computer science increased by almost tenfold while over the same period electrical engineering degrees increased by just over ten percent (National Science Foundation, 2011). While electrical engineering was an entree into high technology occupations in the past, by the mid-1980s undergraduates may have decided that the rapidly growing field of computer science offered a more direct path to these jobs. However, the same decline in bachelor's awards observed in electrical engineering also occurred in computer science during the late 1980s and early 1990s[13]. This contemporaneous decline in bachelor's degrees suggests that whatever caused the decline in electrical engineering (and therefore total engineering) awards was a likely culprit in the decline of computer science awards as well.

In section 1.2 it was noted that wages earned by both electrical engineering and computer science majors increased in the early 1980s, falling in the mid-1980s. Card and DiNardo (2002) interpreted the subsequent decline in wages as evidence against skill-biased technological change, but the wage changes offer a consistent explanation of the strong increase in electrical engineering (and computer science) degrees in the mid-1980s. Freeman (1975, 1976) and Ryoo and Rosen (2004) demonstrate that engineering labor supply is highly sensitive to wages, with a lag for the time spent in training. The wage increase for these graduates in the early 1980s is a plausible explanation for the increased enrollment of electrical engineers a few years later. These enrollments then declined as the glut of new electrical engineers on the market drove down relative wages, as observed by Card and DiNardo (2002). This traditional cobweb dynamic of wages and degree awards implies that new demand for electrical engineers and computer scientists in the early 1980s offers an explanation of trends in bachelor awards through the mid-1980s. The obvious candidate for a change in demand during this period is the introduction of the IBM PC in 1981, and the rise of personal computers generally in the early 1980s, which introduced expectations of strong job opportunities in computers[14]. While career prospects in the early 1980s were promising with the emergence of the PC, they weakened by the late 1980s with the shake-out in the minicomputer industry and the increased reliance on commercial off the shelf technology (COTS) for defense acquisitions which required less in-house engineering and development.

[13] Authors' calculations from the IPEDS.

[14] For example, in the November 1983 *Monthly Labor Review*, Richie, Hecker, and Burgan projected that even under low-growth estimates, employment in the computer industry and other "high technology" industries was expected to grow faster than total employment.



Source: Authors' calculations from engineering degrees in the IPEDS, 1980-2008. Data are unavailable in 1999, and are linearly interpolated for these years.

The most notable characteristic in the trends of mechanical, civil, and chemical engineering bachelor's awards during this time period was a modest pro-cyclicality, with peaks in 1994, 1996, and 1997, after troughs in 1991, 1990, and 1990, respectively. The pro-cyclicality 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 a loose labor market. These enrollees eventually graduate, usually four years later, in a labor market that is stronger as a result of economic recovery. Graduate trends, as opposed to counter-cyclical enrollment trends, are relatively pro-cyclical. This is essentially an explanation of business cycle forces that push youth into engineering (and other) degrees. However, anticipation of future growth can also attract students to fields that provide skills in demand during economic recoveries. These three cyclical fields (mechanical, civil, and chemical engineering) make up a substantial share of total engineering bachelor's awards. While far more electrical engineers were supplied by four year degree programs in the 1980s than any other field, by 1995 roughly the same number of electrical and mechanical bachelor's degrees have been produced each year. By 2005 mechanical awards exceeded electrical engineering awards. In 2008, mechanical, civil, and chemical engineering awards made up almost half of all engineering bachelor's degrees[15].

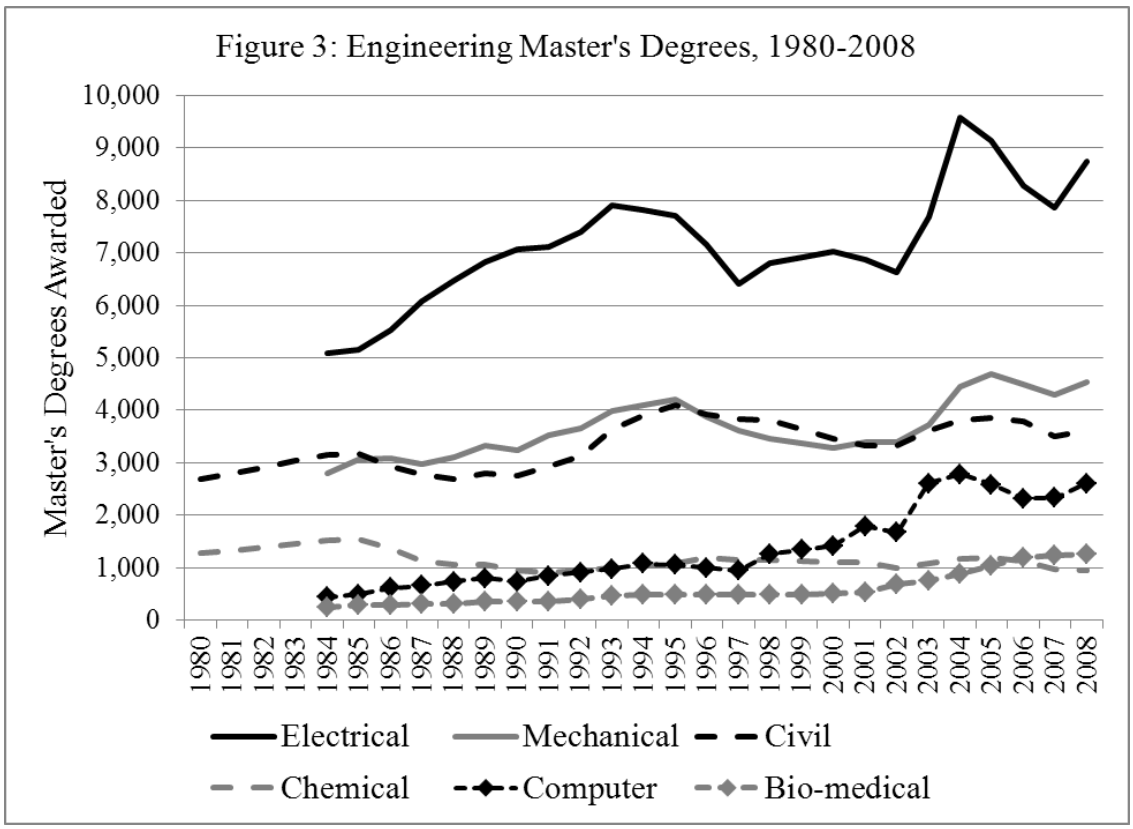
The two smaller fields presented in Figure 2, computer and biomedical engineering, are of interest because of their recent and prospective growth. Neither exhibits the cyclicality of mechanical, chemical, or civil engineering, nor do they display the more idiosyncratic

[15] Since some engineering degrees do not specify a field, it is plausible that more than half of all college graduates with engineering degrees graduate with proficiency in mechanical, civil, or chemical engineering.

fluctuations of electrical 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. Computer engineering programs primarily offer training in hardware engineering. Software engineers, who were even more exposed to the dot-com bubble, would be more likely to hold computer science degrees (if they hold a degree relevant to the field at all). 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 school, due to the significant role that advanced medical equipment and therapies play in modern medicine. 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 awards over the last thirty years, there was much steadier growth in graduate education in engineering. Since 1980, the number of master's degrees in engineering has doubled, while doctorates have more than doubled. Trends in master's awards in the six engineering field highlighted for bachelor's degrees are presented in Figure 3, below. The sharp decline in electrical engineering bachelor's degrees in the late 1980s is non-existent for master's degrees, and while there is a slight cyclicality in the mechanical and civil engineering award trends, a pattern of steady growth is found consistently across all fields.



Source: Authors' calculations from engineering degrees in the IPEDS, 1980-2008. Data are unavailable in 1999, and are linearly interpolated for these years.

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 non-engineering 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 2008 were employed in academia, compared to forty six percent of those with a doctorate in one of the natural sciences[16]. The disparity is comparable for master's degrees. Among the population of terminal engineering master's degree holders, only six percent worked in academia in 2008 (with eighty three percent in the private sector), while twenty one percent of those holding terminal master's degrees in the natural sciences work in academia. For engineers, graduate education is primarily a human capital investment meant to prepare graduates for more specialized work or managerial responsibilities in the private sector and government than is possible with a bachelor's degree.

The growth in graduate awards suggests a persistent demand for engineers with a graduate education, comparable to the high returns to a college in the last quarter of the twentieth century analyzed by Goldin and Katz (2008). They provide a simple supply and demand framework for estimating the relative demand for more and less educated workers that can be used to understand the changing wage premium enjoyed by engineers holding a graduate degree. The equilibrium condition for a constant elasticity of substitution production function with two factors (engineers with a bachelor's degree, and engineers with a graduate degree) allows for the estimation of an elasticity of substitution between the two classes of engineers. Regressing the

[16] Authors' calculations from the 2008 SESTAT.

log of the wage premium on the log of the relative supply of engineers with a graduate degree provides the negative reciprocal of the elasticity of substitution between the two groups of engineers. One of the challenges of empirically implementing this framework using data from the SESTAT surveys is that only seven years of data are available. However, the high explanatory power of this approach (Goldin and Katz (2008) report R^2s of over 0.91 for their college wage premium estimates) and the large increase in the production of graduate degrees in engineering over the study period seems to justify its use as a "back of the envelope" assessment.

The log salary premia and the log supply premia of those holding graduate degrees in engineering over those with undergraduate degrees from the SESTAT data is provided in Table 6, below. A simple regression of the relative salary on supply produces an implied elasticity of substitution between undergraduate and graduate engineers of $\sigma = 3.92$ (the t-statistic for this estimate is high, -6.56, and the adjusted R^2 is 0.875, even with the sample size of seven years). This is somewhat higher than the elasticity of substitution between high school and college labor produced by Goldin and Katz (2008) - suggesting that it is easier to substitute an engineer with a bachelor's degree for an engineer with a master's degree than it is to substitute a high school graduate for a college graduate - but it is much lower than their estimated elasticity of substitution between high school graduates and high school dropouts.

Table X: Engineering Graduate Degree Wage Premium and Relative Supply, 1993-2008

	$\ln(salary_{graduate}/salary_{undergraduate})$	$\ln(supply_{graduate}/supply_{undergraduate})$
1993	0.194	-0.636
1995	0.196	-0.587
1997	0.188	-0.537
1999	0.178	-0.485
2003	0.135	-0.421
2006	0.147	-0.394
2008	0.122	-0.316
Implied σ = 3.923**;** **t-statistic** = -6.56**;** **Adjusted R^2** = 0.875**;** **RMSE** = 0.011		

Source: Authors' calculations from SESTAT 1993-2008. The sample is restricted to employed respondents who earned a bachelor's degree or higher in engineering who are employed as engineers, and is weighted to be nationally representative.

Given the sample restrictions, the regression itself is purely illustrative[17] of the persistence of the relationship beteen the salary premium enjoyed by engineering graduates and trends in the production of new masters and doctorates in engineering. The inability of employers to easily substitute bachelor's degree holders for graduate degree holders and the wage premium enjoyed by graduate degree holders for the last two decades explains the strong, persistent growth in master's degree awards in the IPEDs data, even during periods when bachelor's awards were stagnating. Between 1993 and 2006, the increasing relative supply of graduate degree holding engineers narrowed the gap in salaries between bachelor's and graduate degree holders over this time period. The very different patterns of degree trends by award level presented in Figure 1 seems to have its root in the demand for more engineers with more extensive and more specialized education.

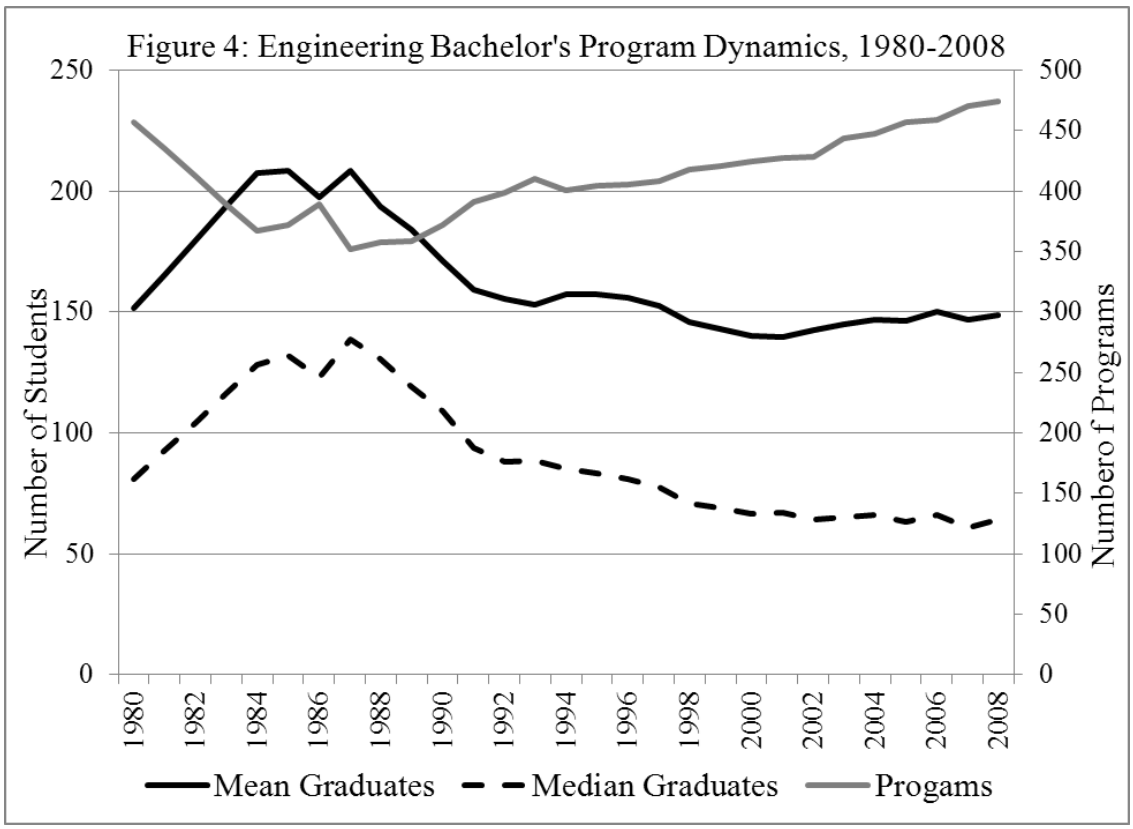
1.4 Engineering Program Dynamics

[17] And the point estimate for the elasticity of substitution itself should be interpreted with extreme caution.

Several decades of empirical literature on the science and engineering workforce suggests that short run labor supply is inelastic, but that the supply of engineers is more responsive to shifts in demand in the long-run. The reason for this dynamic is simple: engineers take several years to train (Freeman 1975, 196), and older engineers who have moved out of the field have a hard time moving back in (Biddle and Roberts 1994). These findings have been confirmed more informally in this chapter. Since adjustments in the production of new engineers play such a crucial role in adjustments of engineer supply, the reaction of institutions of higher education to market forces is particularly relevant to the functioning of the engineering labor market. In addition to simply producing new engineers, this market intermediary role for engineering departments is also shaped by the asymmetry of information between students and professors about the pedagogy, subject matter, and job prospects associated with engineering (Romer 2000). Understanding the role of engineering degree programs is therefore an important part of understanding the functioning of the engineering labor market. Using data from IPEDS, this section will answer the question of how engineering departments respond to changes in the demand for engineers.

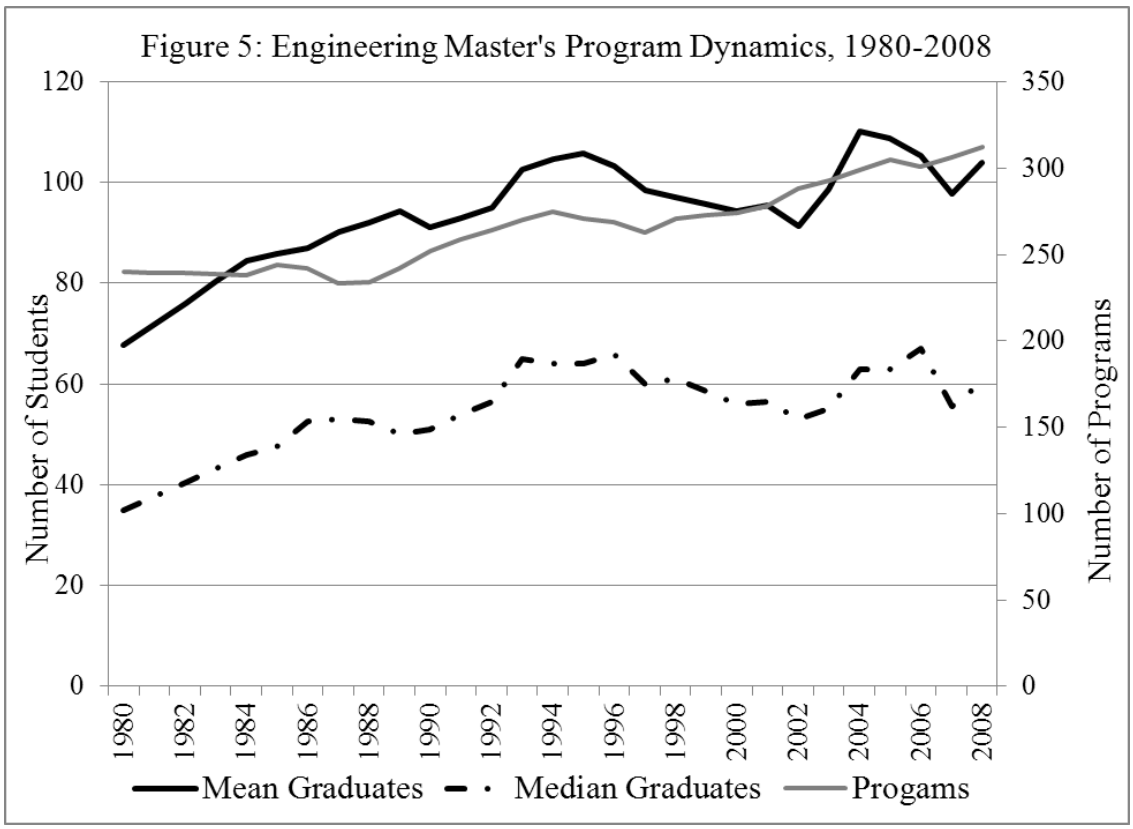
1.4.1 Trends in the size of engineering programs

Section 1.3 noted that bachelor's awards in engineering increased in the early 1980s, falling off sharply (primarily due to a decline in electrical engineering awards) in the late eighties. The production of engineering undergraduates plateaued through the 1990s, but has been increasing slowly over the last decade. What is left ambiguous in these graduation trends is the margin on which which engineering degree programs have adjusted supply. One option is for existing bachelor's degree programs to increase or decrease the number of new engineers they produce; the intensive margin. A second possibility is that new engineering degree programs emerge or old programs stop producing engineers in response to the demand for graduates; the extensive margin. Average changes on these margins (the size and number of engineering degree programs) are presented in Figure 4, below.



Source: Authors' calculations from engineering degrees in the IPEDS, 1980-2008. Data are unavailable between 1980 and 1984, or in 1999, and are linearly interpolated for these years.

The growth in bachelor's awards in the early 1980s was due solely to an increase in the average size of the graduating class of engineering departments, since the number of these departments actually declined over this period. The mean graduating engineering class size increased by over a third, from 152 in in 1980 to 209 in 1985. While some of this increase was due to the closing of smaller engineering programs (105 engineering bachelor's programs closed or temporarily produced zero graduates from 1980 to the trough year of 1987), the growth in continuing programs was sufficient to guarantee a net increase in graduates of over 11 percent. In the middle of the decade this trend slowed and reversed, shifting to a steady increase in the number of engineering programs for the next two decades. However, while the number of engineering programs was growing, the average graduating class size reversed its gains from the early 1980s. Every year from 1987 to 1991, the mean graduating class size fell by at least 5 percent, with much of the decline concentrated in electrical engineering. This preciptious fall in class size moderated in the early 1990s, when the production of new engineers stabilized at just above 60,000 annually for the duration of the decade.



Source: Authors' calculations from engineering degrees in the IPEDS, 1980-2008. Data are unavailable between 1980 and 1984, or in 1999, and are linearly interpolated for these years.

Adjustments on the intensive and extensive margins of graduate engineering programs over the last thirty years have been quite different from these adjustments in undergraduate programs. Consistent with the stable growth in graduate awards, both the number of graduate programs and the average graduating class size increased steadily from 1980 to 2008. The growth in the number of engineering graduate programs did not begin to grow in earnest until 1989, so that growth in master's degrees and doctorates during the 1980s was primarily borne by growing graduating class size.

1.4.2 Characteristics of growing and shrinking programs

In the previous section trends in the supply of new engineers were decomposed into intensive and extensive growth at the university level. However, considerable churning in engineer production also occurs within and between schools at the program level. For example, a stable production of new engineers at a particular school may be the result of a decline in electrical engineering awards and an increase in biomedical engineering awards. To characterize these patterns, Table 7 presents information on engineering programs whose graduating classes grew or shrank over three periods: (1.) the period of decline in the award of undergraduate degrees in engineering from 1986 to 1992, (2.) the period of stability in undergraduate engineering degrees from 1992 to 2001, and (3.) the period of growth in these degrees from 2001 to 2009.

In this section, an "engineering program" is defined by the designated Classification of Instructional Programs (CIP) codes in the IPEDS data. These are the same codes used to identify

the engineering field of graduates in earlier sections. Thus, a single university may have multiple programs as defined in this section, because the CIP codes may not always reflect the organizational structure of the departments themselves. Table 7 uses information on graduating class sizes for electrical, mechanical, civil, chemical, computer, and biomedical engineering programs at all universities in the IPEDS sample, the same universe of engineering fields considered in Section 1.3. Programs which graduate the same number of students at the beginning and end of these periods are not included in Table 7, but they represent a small portion of all programs.

Table 7: Growing and shrinking engineering program graduating classes in selected fields

	Growing			Shrinking		
	'86-'92	'92-'01	'01-'09	'86-'92	'92-'01	'01-'09
	Bachelor's Programs					
Field (pct. growing or shrinking)						
Electrical	28.52	29.02	43.25	70.79	68.77	53.07
Mechanical	34.52	42.39	76.27	63.49	55.07	21.36
Civil	42.53	43.48	76.89	55.20	51.74	21.43
Chemical	14.65	82.50	41.10	81.53	16.88	58.28
Computer	54.81	77.78	53.82	43.27	21.64	45.38
Bio-medical	51.43	87.50	90.91	37.14	12.50	6.06
Mean size at start	27.19	24.61	25.53	69.84	55.79	48.60
Mean size at end	42.41	42.13	43.40	46.15	35.30	33.62
Mean pct. student visa at start	--	--	7.07	--	--	9.29
Mean pct. student visa at end	--	7.57	5.33	--	8.61	7.64
	Master's Programs					
Field (pct. growing or shrinking)						
Electrical	75.98	39.09	68.51	21.57	57.27	29.36
Mechanical	62.77	40.61	68.75	32.45	55.33	25.00
Civil	51.83	47.59	60.67	43.90	47.59	35.39
Chemical	22.14	52.27	38.52	67.18	41.67	54.81
Computer	72.92	77.50	62.50	22.92	22.50	34.38
Bio-medical	60.78	63.38	81.73	35.29	33.80	16.35
Mean size at start	14.72	12.84	13.47	22.98	26.01	25.31
Mean size at end	25.88	24.03	30.03	14.80	15.98	14.48
Mean pct. student visa at start	--	--	39.51	--	--	43.11
Mean pct. student visa at end	--	40.74	40.13	--	41.52	41.37
	Doctoral Programs					
Field (pct. growing or shrinking)						
Electrical	75.00	48.87	38.30	16.67	39.85	53.90
Mechanical	79.82	46.28	38.28	17.43	46.28	56.25
Civil	59.38	50.93	46.02	28.13	44.44	49.56
Chemical	58.51	42.86	35.71	32.98	44.90	52.04
Computer	74.07	53.85	66.00	18.52	38.46	30.00
Bio-medical	68.42	66.67	62.16	23.68	20.37	36.49
Mean size at start	4.07	4.81	3.90	5.29	8.24	8.43
Mean size at end	9.00	8.67	8.74	2.93	4.86	1.35
Mean pct. student visa at start	--	--	54.59	--	--	54.06
Mean pct. student visa at end	--	52.54	56.38	--	56.13	62.73

Source: Authors' calculations from 1986-2009 IPEDS data.

Growth and decline in bachelor's degrees at the engineering program level varies considerably across fields and time periods. From 1986 to 1992, a period of retrenchment for most undergraduate engineering programs, the majority of computer and biomedical engineering programs were increasing their production of engineers. Marked declines in electrical engineering were noted above, but chemical engineering programs also showed weakness over this period with 15 percent growing and 82 percent shrinking. During the 1990s growth picked up considerably in chemical engineering programs, with 83 percent increasing the number of bachelor's awards produced. Civil and electrical engineering programs showed less change over this period. From 1992 to 2001, 29 percent of all electrical engineering programs grew, while 69 percent shrank, roughly the same distribution from the 1986 to 1992 period.

The increase in the share of computer and biomedical programs growing their graduating class continued over the 1992 to 2001 period, during which 78 percent of computer engineering programs and 88 percent of biomedical programs grew. This decade and a half of strong growth in computer engineering tapered off after the dot-com bubble, when the percent of growing programs dropped from 78 percent to 54 percent. Biomedical engineering did not follow this pattern. Building off of the tremendous growth in NIH funding and health expenditures, 91 percent of undergraduate biomedical engineering programs increased the size of their graduating class between 2001 and 2009. While the persistence of growth in the biomedical field is an important trend, the performance of traditional fields like mechanical and civil engineering has also notable during the 2000s. Over 75 percent of the programs in both of these fields increased their graduating class size between 2001 and 2009. This level of growth was not replicated in electrical or chemical engineering.

Generally speaking, smaller programs grow and larger programs shrink. Although this can be indicative of a regression toward the mean, there is evidence of a trend decline in average graduating class size at the program level, just as there was at the university level in Figure 4. Although the mean size of growing programs at the end of the period is persistent from 1986 to 2009, the mean size at the end of the period for shrinking programs declines from 46 to 34 students. At both the university and program level, then, undergraduate engineering cohort sizes have declined. Information in the IPEDS on students on holding a student visa are not available until halfway through the 1992 to 2001 period. In both growing and shrinking programs, holders of student visas make up a lower share of graduates by the end of the 2001 to 2009 period than they did at the beginning. This suggests that although only a small percentage of undergraduate engineering enrollment is attributable for immigrants on student visas in the first place, there was a disproportionate decline in graduates on student visas in shrinking programs, and a disproportionate increase in domestic graduates in growing programs. In other words, holders of student visas shared in the growth of expanding undergraduate programs at a lower rate than natives, and disproportionately bore the brunt of the decline in shrinking programs.

Reflecting the strong aggregate growth in graduate engineering degree awards, masters and PhD degree programs across engineering fields were more likely to be growing than undergraduate programs. The most notable exception seemed to be chemical engineering programs, which were more likely to be shrinking in some periods (particularly masters level programs). All graduate programs exhibited the same regression to the mean behavior observed in the undergraduate programs, with shrinking programs having a larger initial number of graduates than growing programs. The performance of holders of student visas in growing and shrinking programs differed between masters and PhD programs. Student visas holders comprised a smaller share of shrinking masters degree programs in 2009 than they did in 2001,

suggesting that these students bore a greater amount of the reduction than domestic students. In growing master's programs immigrants modestly increased their share of the program. In contrast, both growing and shrinking PhD programs saw much high student visa shares in 2009 than in 2001, particularly among shrinking programs. This suggests (contrary to the case of master's and bachelor's degrees) that domestic students bore the brunt of shrinking doctoral engineering programs.

1.5 Conclusion

Engineers are fundamental to a well-functioning, developed economy. The generation and maintenance of modern technology would be unthinkable without engineers, who operate as the intermediary between scientific advances and improvements in everyday life. As such, economists 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 precisely these issues. The first section considered some major factors in the demand for engineers. Engineers are in demand by a large variety of employers. Some fields, such as civil and electrical engineering, are in demand across a wide variety 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 found employment in independent engineering firms, reflecting broader trends in outsourcing in the economy. Engineers are not exclusively in demand in technical capacities; there is a strong tradition of engineers moving into management positions as they age. However analysis of National Science Foundation data in this chapter finds that over the last two decades progressively fewer individuals with engineering degrees are working as managers and a larger share of working engineers are taking on management tasks and responsibilities in addition to their technical work. This is consistent with qualitative research findings of a "flattening" of occupational hierarchies, and it is of particular consequence for historic engineering career trajectories. 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 biological 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, so that little additional employment from younger workers is in demand.

The next section considered the production of new engineers by colleges and universities. The behavior of engineering bachelor degree awards varied substantially across fields. Civil and mechanical degrees, for example, exhibited a strong cyclicality while 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 which had little to do with the business cycle. The fluctuation of electrical engineering degree production does not seem to be heavily influenced by trends in computer science education. 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. A preliminary analysis of the wage premium enjoyed by engineering graduate degree holders suggests that high labor market returns to are an important reason for the steady growth in graduate awards.

The first section of the chapter highlighted the various sources of demand for engineers and the variability of demand for different fields over time, while the second section provided evidence that students are responsive to these changing demand conditions. An often neglected question is how colleges and universities respond as institutions to changing demand for engineers. This question is taken up in the final section of the chapter. Over the last twenty years, undergraduate and graduate engineering programs seem to respond differently to changes in the aggregate production of engineering students. For most of the 1990s the production of undergraduate engineers remained stable, with growth in these degree awards occurring only in the last ten years. These changes were accommodated by engineering degree granting programs by increasing the number of engineering programs, but reducing the average size of those programs. In contrast, the steady growth of engineering degrees at the graduate level has been accommodated by expansion on both the extensive and intensive margins. New graduate programs have opened while the average graduate program has expanded in size. Considered separately, growing and shrinking programs generally reflect the field-level trends reviewed in section 1.3.

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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