IRLE
Institute for Research on Labor and Employment

IRLE WORKING PAPER
#163-07
June 2008 Updated

Is There a Shortage of Engineering Talent in the U.S.?

Clair Brown and Greg Linden

Cite as: Clair Brown and Greg Linden. (2008). “Is There a Shortage of Engineering Talent in the U.S.?” IRLE Working Paper No. 163-07. http://irle.berkeley.edu/workingpapers/163-07.pdf

Institute for Research on Labor and Employment

Institute for Research on Labor and Employment Working Paper Series

(University of California, Berkeley)

Year 2008 *Paper iirwps-163-07*

Is There a Shortage of Engineering Talent in the U.S.?

Clair Brown
University of California, Berkeley

Greg Linden
University of California, Berkeley

Is There a Shortage of Engineering Talent in the U.S.?

Clair Brown and Greg Linden
Center for Work, Technology, and Society, IRLE
University of California, Berkeley
February 2008

This paper is based on research conducted for our forthcoming book, *Change Is the Only Constant: How the Chip Industry Deals with Crisis.* Clair Brown is professor of economics and director of the Center for Work, Technology, and Society (IRLE) at University of California, Berkeley; Greg Linden is senior research fellow at the Center for Work, Technology, and Society at UC Berkeley. Yongwook Paik provided excellent research assistance. The authors would like to thank the Alfred P. Sloan Foundation, the Institute for Research on Labor and Employment at UC Berkeley, and the Institute for Technology, Enterprise and Competitiveness (ITEC/COE) and Omron Fellowship at Doshisha University, Japan, for funding. We are grateful to Ben Campbell, Bob Doering, David Ferrell, Michael Flynn, Gartner Dataquest, Ron Hira, Dave Hodges, Rob Leachman, Daya Nadamuni, Elena Obukhova, Devadas Pillai, Semiconductor Industry Association, Chintay Shih, Gary Smith, Bill Spencer, Strategic Marketing Associates, Yea-Huey Su, Tim Tredwell, and C-K Wang for their valuable contributions. Melissa Appleyard, Hank Chesbrough, Jason Dedrick, Rafiq Dossani, Richard Freeman, Deepak Gupta, Bradford Jensen, Ken Kraemer, Frank Levy, B. Lindsay Lowell, Jeff Macher, Dave Mowery, Tom Murtha, Tim Sturgeon, Michael Teitelbaum, and Eiichi Yamaguchi, as well as participants at the NAE Workshop on the Offshoring of Engineering, the 2005 Brookings Trade Forum on Offshoring of White-Collar Work, the Berkeley Innovation Seminar, and the Doshisha ITEC seminar series provided thoughtful discussions that improved the paper. We are especially grateful to Gail Pesyna at the Sloan Foundation for her long-running support of, and input into, our research. The authors are responsible for any errors.

Is There a Shortage of Engineering Talent in the U.S.?
Clair Brown and Greg Linden

> "The fast-paced evolution and continued growth of the semiconductor industry in the U.S. demands a pipeline of talented and highly-trained workers. What's flowing through that pipeline is becoming increasingly insufficient." – Kevin Lyman, Sr VP, Human Resources, AMD.[1]

> "Our immigration policies are driving away the world's best and brightest precisely when we need them most." -- Bill Gates before a Senate committee on March 7, 2007.[2]

Introduction

High-tech companies have been issuing the "crisis warning" about engineering shortages for at least the past two decades. AMD's and Microsoft's warnings quoted above are only two in a long line of warnings issued by companies and government-sponsored panels.

At the same time, we saw in Crisis 4 that the price squeeze that led the U.S. industry to globalize its supply chain also led to the fear that U.S. engineers are losing jobs to lower-cost foreign engineers.

In this chapter we ask if the U.S. is facing a talent crisis by looking critically at what is happening to high-tech engineering employment and earnings in the U.S. How can the U.S. fear loss of engineering jobs while experiencing a shortage of engineers? Experts cannot agree if the U.S. is educating or granting visas to too few or too many engineers and scientists.[3] This is partly because economists find it hard to believe a shortage exists in a labor market when real earnings are not rising across the board, as we will see is generally the case in the high-tech engineering labor market. Also the debate reflects the different positions of engineers and their employers on the proper government policies to regulate immigration and fund higher education of engineers and scientists.

Economists have generally believed that any imbalance in the engineering labor market is short lived while the market equilibrates through changes in earnings and in the supply of newly educated engineers--earnings increase (or decrease) and result in an increase (or decrease) in supply of engineers and decrease (or increase) in demand. Eventually the supply of engineers should satisfy the demand, although the transition requires time to train new engineers or to retire or relocate experienced engineers.

At the heart of the public debate is the fact that engineers and their employers represent the two sides of the marketplace: employers want low-cost hard-working engineers with state-of-

[1] As quoted in "Overcoming America's Semiconductor Workforce Crisis" *Design News* 12/14/2006
[2] http://www.informationweek.com/showArticle.jhtml?articleID=197800800 - March 7, 2007
[3] See for example Richard B. Freeman (2003, 2005); Task Force On The Future Of American Innovation (2005); National Research Council (2000, 2001); William Butz et al (2004).

the-art knowledge, and engineers want well-paid challenging jobs that provide continual skill and career development. Employers prefer a surplus of engineers in their hiring queue in order to find new hires with exactly the right state-of-the-art skills and without competition from other employers that drives up earnings. Engineers prefer a shortage of engineers, so employers are willing to (re)train their current workforce in the required skills, or the engineers have challenging job options with other employers, which tends to drive up earnings.

The U.S. government plays a powerful role in the U.S. engineering labor market and can speed up or slow down the transition towards equilibrium. Here we focus on the impact on the supply of U.S. engineers through visa regulations, which determine the number of foreign engineers and foreign students coming into the U.S. These policies can quickly increase or decrease the supply of engineers and directly affect the bargaining power of engineers and their employers. No wonder the two sides present very different arguments to the Federal Government about how many foreign engineers should be allowed to study and work in the U.S.

Our own interviews with semiconductor executives since the early 1990s indicate that companies worry about a "future shortage" even as they report being able to recruit excellent engineers. Companies also indicate that the educational requirements are increasing, and most want to hire only MS (or PhD) engineers for design and product or process development. Their worries about hiring talented engineers seem to reflect their fears that competition will push salaries up for those with graduate training, and of course the companies would prefer that the graduate premium stay low.

This chapter analyzes the U.S. labor market for semiconductor engineers—the earnings and employment opportunities over the past five years, the career paths engineers face as they age, and the returns to investing in advanced degrees. Then we look at the influence of three important forces on the demand and supply for semiconductor engineers—technological change, graduate education practices, and H-1B visa policy. In particular we explore how U.S. supply of high-tech engineers is affected by the global brain circulation and U.S. policies in higher education and immigration. We close by discussing the outlook for U.S. engineers and their companies.

The U.S. Labor Market for Engineers

In a highly cyclical industry like semiconductors, we often have a hard time disentangling the cyclical fluctuations from the long-run trends. Just since 2000, the U.S. semiconductor industry has experienced ups and downs—a severe recession in 2001, a recovery that stalled in 2004, a large decline in U.S. venture funding for start-ups that began to pick up in 2006, an increase and then decrease in the number of H-1B visas, and a drop and then recovery in foreign student applications to U.S. graduate engineering schools since 9-11. Meanwhile U.S. firms were busy opening design centers offshore, especially in India. The long-run impact on U.S. engineering jobs from this confluence of forces and the engineers' responses are hard to predict, and this caveat should be borne in mind in any analysis of the labor market for semiconductor engineers.

Because of the complexity of the situation, we look at multiple data sources on U.S. semiconductor engineers to see how they are faring.[4] First we use Occupational Employment

[4] To identify trends in the employment and earnings of semiconductor engineers, we use three data sets that have different strengths and weaknesses. The Bureau of Labor Statistics' Occupational Employment Statistics data (obtained online at

Statistics (OES) data from firms to look at how employment and earnings of various types of engineers have changed during 2000 to 2005, and how engineers have fared compared to other professionals. Then we use American Community Survey (ACS) data from households to see how engineers with different levels of education and at various stages of their careers were doing in 2005. We than use a Longitudinal Employer-Household Dynamics (LEHD) data set that links employees and firms to look in some detail at career paths of semiconductor workers, as they piece together the jobs offered by firms over the 1992 to 2002 period.[5] Together these data sets provide us with a rich and complex view of the high-tech engineering labor market.

---

www.bls.gov/oes/home.htm) provide a large sample collected from establishments that report detailed occupational characteristics. However comparison of data across years is not exact, since OES is designed for cross-section comparisons and not for comparisons across time because of changes in the occupational, industrial, and geographical classification systems, changes in the way data are collected, changes in the survey reference period, and changes in mean wage estimation methodology, as well as permanent features of the methodology. More details can be found at http://www.bls.gov/oes/oes_ques.htm#Ques28. Also educational characteristics are not given. The American Community Survey (ACS) (http://www.census.gov/acs/www/), which is a relatively new household survey that began in 1996 in order to update the Census between decennial surveys, provides detailed occupation and industry characteristics as well as education, and so it is much better suited for our labor market analysis. However the sample size is not adequate for detailed analysis until 2002 and later years. To look at the jobs provided by firms and workers' career paths, we use the Census Bureau's Longitudinal Employer-Household Dynamics (LEHD) that links employers and employees over the period 1992-2001.

[5] For a more detailed comparison of the OES and ACS data, see Brown and Linden, "Semiconductor Engineers in a Global Economy" NAE (2006). For detailed analysis of career paths, see Brown et al, Economic Turbulence (2006).

Employment and Earnings. Nationally in 2005, 2.4 million engineers[6] averaged yearly earnings of $63,920 (see Table 1). Another 2.9 million engineers had jobs in computer occupations with average yearly earnings of $67,100.

The semiconductor industry[7] employed 450,000 U.S. workers in 2005, with 27% in engineering and computer occupations (or 17% if lower-level sub-categories such as technicians and computer support are excluded). These two occupation groups do not include managers, who are 8.2% of employment.

A significant percentage of engineers work in the semiconductor industry, especially in the most relevant sub-categories—12% of electronics engineers, 7.3% of electrical engineers, 18% of computer hardware engineers, 5.8% of industrial engineers, and 2% of computer software (applications and systems) engineers. Together these six occupations account for 85% of engineering jobs in the semiconductor industry.[8]

Although national employment in engineering occupations, which includes a category called "technicians" for workers with less than a BS degree, fell 7.5% from 2000 to 2005, engineering jobs in the semiconductor industry fell a surprising 28%.[9] However when we look at the major categories for semiconductor engineers, we see that jobs increased for electrical engineers (6%), electronic engineers (11%), and computer hardware engineers (141%), while jobs for industrial engineers fell 12%, which is the only specialty where job growth for semiconductor engineers was lower than for comparable engineers nationally.

[6] The OES's broad category of "Architecture and Engineering" (Standard Occupational Classification 17-0000) is the occupational category used for engineers, and "Computer and Mathematical" (SOC 15-0000) is the occupational group used for computer scientists.

[7] For the semiconductor industry, we use the North American Industry Classification System (NAICS) 3344 "Semiconductor and Other Electronic Component Manufacturing", which includes relatively low-value components such as resistors and connectors. The most relevant subcategory, "Semiconductor and related device manufacturing" (NAICS 334413), accounted for 39% of employees (and 45% of non-production workers) in the 3344 category in 2003, but occupation-specific data are not available at this level of industry detail. Source: U.S. Census Bureau, "Statistics for Industry Groups and Industries: 2003," Annual Survey of Manufactures, April 2005.

[8] Excluding techs, drafters, and computer support occupations. Only occupations with at least 5000 employees in the semiconductor industry are shown. For example, computer programmers are not shown; there were 3,310 semiconductor programmers in 2000 (average earnings $74,627) and 1,900 in 2005 (average earnings $74,370).

[9] Comparison of 2000 and 2005 is not exact because SIC 367 was used in 2000 for the industry code and NAICS 334400 was used in 2005. The biggest drop in semiconductor engineering jobs occurred in the "Electrical and Electronic Engineering Technicians" sub-category (-62%), which reflects the sensitivity of employment in manufacturing jobs during the recession..

Table 1: Engineer Employment and Earnings, 2000 and 2005

	2000		2005			
	Employment	Avg Annual Earnings	Employment	Avg Annual Earnings	% Change in Employment	% Change in Earnings
Engineering occupations (total)	2,575,620	$54,060	2,382,480	$63,920	-7.50%	18.24%
Engineers in SC	132,150	$52,100	95,520	$68,720	-27.72%	31.90%
Electrical engineers (total)	162,400	$66,320	144,920	$76,060	-10.76%	14.69%
Electrical eng in SC	10,050	$69,560	10,620	$82,400	5.67%	18.46%
Electronic engineers (total)	123,690	$66,490	130,050	$79,990	5.14%	20.30%
Electronic eng in SC	14,170	$65,400	15,700	$82,430	10.80%	26.04%
Aerospace Engineers (total)	71,550	$69,040	81,100	$85,450	13.35%	23.77%
Chemical Engineers (total)	31,530	$67,160	27,550	$79,230	-12.62%	17.97%
Civil Engineers (total)	207,080	$58,380	229,700	$69,480	10.92%	19.01%
Computer Hardware Engineers (total)	63,680	$70,100	78,580	$87,170	23.40%	24.35%
Hardware eng in SC	5,990	$70,780	14,440	$89,870	141.07%	26.97%
Industrial Engineers (total)	171,810	$59,900	191,640	$68,500	11.54%	14.36%
Industrial eng in SC	12,580	$64,420	11,030	$74,250	-12.32%	15.26%
Mechanical Engineers (total)	207,300	$60,860	220,750	$70,000	6.49%	15.02%
Computer Occupations (total)	2,932,810	$58,050	2,952,740	$67,100	0.68%	15.59%
Computer occp in SC	27,080	$66,660	28,770	$77,800	6.24%	16.71%
Computer programmers (total)	530,730	$60,970	389,090	$67,400	-26.69%	10.55%
Programmers in SC	3,310	$65,800	1,900	$74,370	-42.60%	13.02%
Software eng, applications (total)	374,640	$70,300	455,980	$79,540	21.71%	13.14%
Software eng (apps) in SC	5,890	$72,680	8,250	$86,860	40.07%	19.51%
Computer software eng, systems (total)	264,610	$70,890	320,720	$84,310	21.20%	18.93%
Software eng (systems) in SC	8,280	$76,660	7,090	$90,820	-14.37%	18.47%

NOTE: SC = Semiconductors at the lowest level of aggregation available from BLS: SIC 367 in 2000 and NAICS 3344 in 2005

Software engineers have become increasingly important in the semiconductor industry (Crisis 3), and semiconductor software jobs grew 6% between 2000 and 2005, while national software employment stagnated. However the growth was in software applications jobs, which grew 40%, while software systems jobs fell 14%.

Of course the years between 2000 and 2005 exhibit variations in employment rather than a smooth increase. For example, applications software engineers experienced strong employment growth in 2003 followed by a dip in employment in 2004, and electrical and electronics engineers experienced a dip in employment in 2003 followed by very strong employment growth in 2004. Nationally the unemployment rate for electrical and electronics engineers attracted attention as it reached 6.2% in 2003, converging for the first time in 30 years with the general unemployment rate, and then falling back in 2004 to a more typical rate of 2.2%.[10]

Engineers in the semiconductor industry typically command a higher salary than their counterparts in other industries. Engineers in the semiconductor industry received average annual earnings that were anywhere from 3% higher for electronic engineers to 9% higher for computer software application engineers compared to engineers nationally. The main six semiconductor engineering specialties all experienced real earnings growth (so average earnings rose faster than the 13% inflation rate over the period[11]). Real (inflation-corrected) growth ranged from 1.9% for industrial engineers to 14% for computer hardware engineers.

These data indicate that the labor market for semiconductor engineers appears to be relatively strong in the five years since the dot.com bust in 2000, when, nationally for all occupations, earnings have mostly stagnated during the economic recovery with income gains going disproportionately to the top 10% (and especially the top 1%). Semiconductor engineers have also experienced better job and earnings growth than engineers in the same specialty in other industries. Although earnings growth was relatively high only for computer hardware engineers and electronic engineers in the semiconductor industry, all six specialties of semiconductor engineers have high average annual earnings, which ranged from $74,250 for industrial engineers to $90,820 for software systems engineers in 2005.

Overall the data indicate that the labor market for high-tech engineers does not seem to be out of balance in either supply or demand. High-tech engineers appear able to move among various industries as demand shifts, and overall wages appear stable. However these average data do not tell the full story, since we don't know how engineers are doing over their careers as they age, or how engineers at the top and bottom of the salary distribution are faring.

Age-Earnings Profiles by Education.[12] We approximate how semiconductor engineers are doing as they age by looking at the earnings of engineers of various age groups in a given year, and this gives us a snapshot of the returns to experience. We use 2005 ACS

[10] Data were provided by Ron Hira. BLS redefined occupations beginning with the 2000 survey covering 1999, but there is no evidence that the redefinition has contributed to the post-bubble unemployment rise. See also "It's Cold Out There", IEEE Spectrum, July 2003.
[11] The CPI-Urban is used to measure inflation. Source: http://data.bls.gov/cgi-bin/surveymost?cu
[12] The analysis using 2005 ACS data extends the analysis using 2000, 2002, and 2004 ACS data in Brown and Linden (2006), which also looked at workers with less than a college degree.. The results represented here for 2005 are consistent with the results from the earlier years, with older engineers doing even worse in 2005 than previous years.

data to look at earnings of engineers ages 21 to 65 years (a proxy for experience) in the semiconductor industry by education (BS, MS/PhD).[13] The 2005 age-earnings profiles of semiconductor engineers with a BS degree (**Figure 1**) and MS/PhD degrees (**Figure 2**) show how engineers at the high (90th percentile), median, and low (10th percentile) points of the salary distribution fare as they age. These results are also shown in Table 2.[14] Of course, we do not know if the returns to experience indicated by the 2005 data are the actual returns experienced by the various cohorts of engineers.

Engineers at the top, middle, and bottom of the salary distribution in both education groups show earnings that increase with experience (age) through prime ages (21-50 years), and then older workers (51-65 years) experienced labor market problems as earnings declined (see figures 1, 2). Only engineers with advanced degrees at the top of the salary distribution did not experience a decline in earnings after age 50.

At least part of that decline in earnings for older engineers can be explained by looking at weeks worked (Table 2). Workers over age 50 are much more likely than workers in their 30s and 40s to work less than a full year (defined conservatively here as less than 48 weeks of paid work). One in six engineers aged 51 to 65 years reported being paid for less than a full year of work in 2005, when the labor market was relatively strong. During the 2002 downturn, more than one in four older engineers had less that a full year of paid work (Brown and Linden, 2005).

The inequality in earnings increases with age (see 90/10 ratio and graphs) with one exception—the earnings inequality is lower for engineers over 50 compared to those in their 40s with a Bachelors degrees, as both earners at the top and bottom of the distribution experience lower earnings. In comparison, the earnings inequality for engineers over 50 with a graduate degrees jumps up. Typically the growing inequality is thought to reflect faster growing pay for the higher performers, and pay for the top earners would be expected to increase as engineers become managers. However we see that pay at the top flattens out with age and pay at the bottom end suffers a sharp drop for these engineers with graduate degrees. The increase in inequality between prime-aged and older engineers reflects holding on at the top and losing ground at the bottom, rather than the top performers doing even better. These profiles indicate that many engineers with college and advanced degrees are facing declining and inadequate job opportunities after age 50.

[13] Age-earnings profiles by education were calculated using the ACS for a sample of workers age 21-65, in industry code 339 (Electronic components and products, comparable to NAICS 3344 and 3346), in a set of occupation codes (selected electrical and electronic, software, and other engineering occupations and selected managerial occupations). We used several different samples of occupation codes in order to test for sensitivity of age-earning profiles to the definition of semiconductor engineer occupations. In the results presented here, we included SOC 172070, 172061, 151021, 151030, 151081, 172131, 172110, 172041, 119041, 113021, 111021, 112020, 113051, and 113061. When we restricted the sample to fewer occupation codes, the age-earnings profiles remained mostly stable, with the earnings of the top 10% increasing for older groups with the inclusion of more managerial occupations. BS includes college graduates who do not have a higher degree; MS/PhD includes workers with a Masters or PhD degree. Workers with professional degrees (e.g., MD, DDS, LLB, JD, DVM) are excluded.

[14] Earnings for n% represents the earnings where n% of observations are below this value and (100 – n)% of observations are above this value. Earnings for 50% represents the median.

Figure 1: 2005 Age-Earning Profile, BS Holders

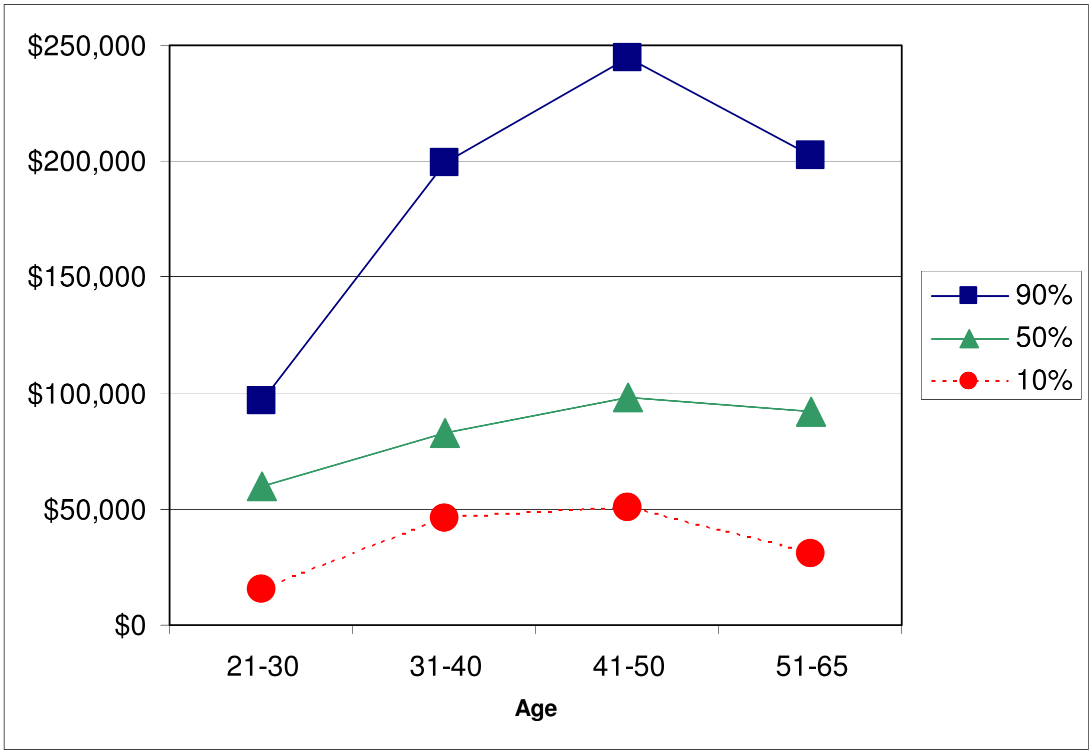


Figure 2: 2005 Age-Earnings Profile, MS and PhD Holders

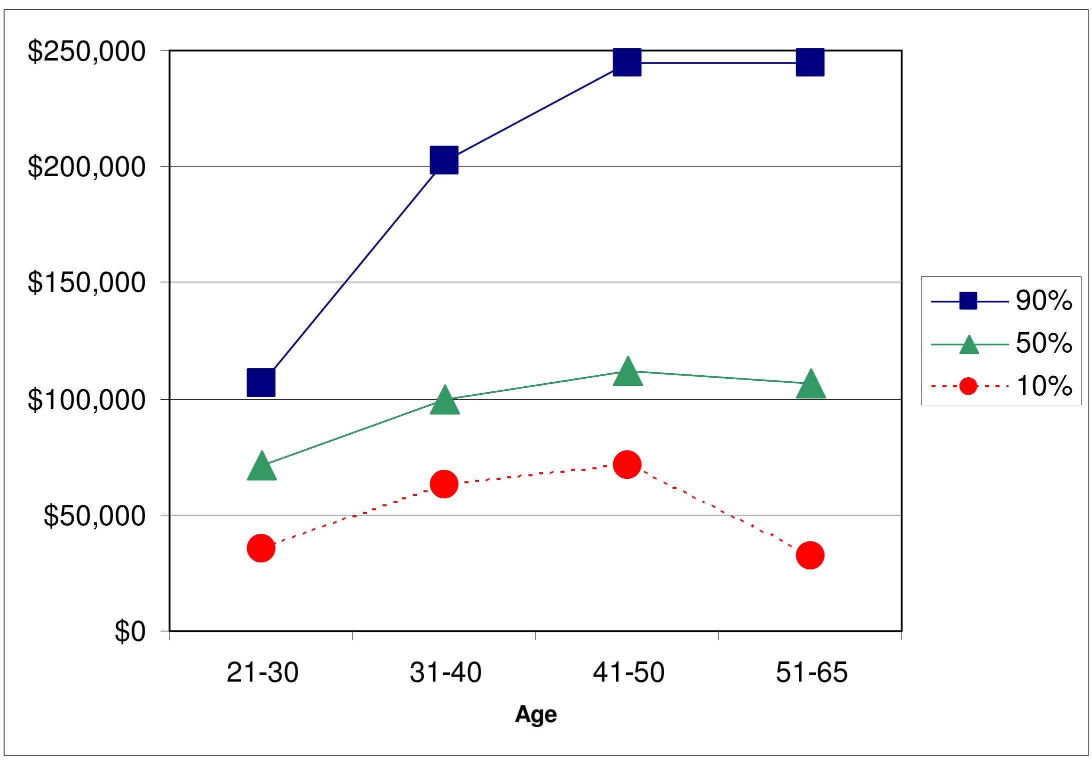


Table 2: Age-Earnings Profile (2005)

		21-30	31-40	41-50	51-65
< Bachelors degree	**10%**	11358	37691	38710	35144
	50%	32597	61120	63667	63157
	90%	62648	91680	99830	96773
	90/10 ratio	5.52	2.43	2.58	2.75
	Mean	35256	61261	71027	63968
Bachelors degree	**10%**	15687	45840	50933	30560
	50%	60102	82512	97792	91680
	90%	96773	199659	244480	202715
	90/10 ratio	2.74	3.26	3.44	3.17
	Mean	58522	95093	121700	101024
Masters or PhD degree	**10%**	35653	63157	71307	32394
	50%	71307	99830	112054	106960
	90%	106960	202715	244480	244480
	90/10 ratio	3.00	3.21	3.43	7.55
	Mean	72791	111742	137356	118549

NOTE: The repetition of earnings in some cells, especially for the 90% group, appears to reflect the data collection, which is done by asking employers to give earnings in specific ranges.

Table 3: Proportion Working Less Than Full Year (48 Weeks), 2005

	Age Ranges			
	21-30	**31-40**	**41-50**	**51-65**
Bachelors degree	20.34%	9.30%	6.61%	17.42%
Masters or PhD degree	17.65%	9.26%	5.99%	17.48%

Note: The value in each cell is the proportion of that age group with the indicated degree who were employed less than 48 weeks in the indicated year.

Returns to education. Although we expect earnings to increase with education, figures 1 and 2 show fairly similar earnings for semiconductor engineers with college degrees and advanced degrees. What is the return to an advanced degree?

In 2005 the graduate degree premium for the typical engineer in the early stage of a career (median earnings at age 31-40) was 21%, but the premium fell to only 15% or so for engineers over 40 (calculated from Table 2). Using the national earnings figures shown above as a guide, we made a rough estimate of the earnings and earnings growth of a semiconductor engineer with a BS degree and one with a PhD up to age 40. We assumed the BS earns $50,000 in his first job (age 21) and earns $90,000 at age 40; the MS/PhD takes three years to complete graduate training and earns $70,000 in her first job (age 24) and earns $105,000 at age 40. If earnings grow at a constant annual rate, the BS engineer's earnings are growing at 3.3% annually, and the MS/PhD engineer's earnings are growing at approximately 2.75% annually.[15] At age 40, the MS/PhD is earnings 17% (or $15,500 more) than the BS engineer, but career earnings are $51,000 lower, since the graduate training involved giving up pay for three years.[16]

The low graduate degree premium indicates that only weak financial incentives exist for domestic engineers to pursue graduate degrees. However the premium for students born abroad in a developing country is much higher since entrance into a graduate program in the U.S. allows them access to much higher paying jobs in the U.S. upon graduation. If they go to work with a BS in their home countries, their pay is a fraction of the U.S. pay, as we saw in India, although the Indian salary may rise very quickly for several years.[17] By coming to the U.S. for graduate training, they dramatically improve their job opportunities, both in the U.S. and abroad, so their graduate degree premium is extremely high. For foreign engineers, obtaining a graduate degree at a U.S. university provides a high-income career relative to what they could earn at home with a domestic BS degree.

For domestic U.S. students, the return to a BS degree provides financial incentives to finish college, with the college graduate experiencing median earnings that are 35% to 84% higher than the earnings of engineers who finished high school but not college in 2005. The typical engineer with a BS degree experienced steady earnings improvements with age until reaching the 50s. In contrast, the typical engineer who did not finish college experienced a jump in earnings between the 20s and 30s, and then median earnings flattened out for engineers over 30 years old.

Summary. Although the high-tech engineering labor market appears strong nationally, the data by age and education indicate that the premium for advanced degrees is not adequate and that older engineers face deteriorating job opportunities. While the entry-level premium for a graduate degree appear to be adequate, the low returns to experience over the engineer's career for graduate degree holders make the returns to the investment in a graduate degree inadequate. The entry-level return to a BS degree and the returns to experience appear adequate for engineers under age 50. However many older engineers with college and advanced degrees are experiencing a troubling drop in real earnings and a decline in hours.

Career Paths for Semiconductor Professionals.

Let's look briefly at the actual career paths of prime-aged (aged 35-54) high-education (college degree and graduate degrees) male semiconductor workers to see if they are consistent with our results based on comparing engineers of different ages.[18] Here workers cannot be broken out by occupation, and so they include engineers as well

[15] At 3% growth rate, the BS earnings would be $85,00 at age 40; at 3% growth rate, the MS/PhD earnings would be $109,000 at age 40.

[16] We assume that the graduate student receives a fellowship that covers tuition and living expenses, which we assume offsets the discounting of the salary stream of the BS for the three years.

[17] According to an executive in an Indo-American design services company, the ratio of a 5-year engineer to a new hire will typically be more than 2–to-1 in India, compared with only 1.3-to-1 in the US (interview, November 2005).

[18] This material is taken from the Sloan-Census project that produced the book *Economic Turbulence* by Brown et al (2006) and related papers (see www.economicturbulence.com). See book chapter 5 for an overview of firms' job ladders and chapter 6 for an overview of worker's career paths in the semiconductor and four other industries (software, finance, trucking, and retail food).

as managers and others. We describe the career paths for these workers by how many jobs they have—one, two, or three jobs over the decade 1992-2001.[19]

Table 4: Semiconductor Career Paths, High-education Men aged 35-54

	Loyalist	Two Jobs	Three Jobs
Initial earnings	$36,084	$22,893	$18,197
Earnings growth (annual)	.059	.048	.047
Simulated earnings (after ten yrs)	$65,207	$36,925	$29,068

- Mean initial earnings (2005 dollars, using the CPI-urban)
- Net annualized earnings growth rate (in log points) across10-year simulation
- Simulated 2001 final average earnings (2005 dollars)

Source: *Economic Turbulence* (Brown et al, 2006), Chapter 6, Table 6.1. Original calculations by authors from Census LEHD data. These career paths are for workers in all occupations in the semiconductor industry, so they include engineers as well as other occupations, over the period 1992-2001. An employee is included in the data set if he has at least one job in the semiconductor industry over the period.

<u>*Career paths.*</u> Semiconductor workers exhibit two distinct types of career paths--loyalists and job changers (see Table 4). Workers who already work for a semiconductor employer with good jobs (high initial earnings and good earnings growth) become loyalists, i.e., they do not change jobs over the decade. Loyalists have career paths that are considerably better than the career paths of job changers.

Job changers have inferior jobs and change jobs, either voluntary or involuntary (we don't know which), to land a better job. These job changers have relatively low initial earnings in a job outside the semiconductor industry, and then experience substantial earnings growth (usually 20 to 30% for younger and 10 to 20% for older workers) by taking a job in the semiconductor industry. The overall earnings growth of two-jobbers and three-jobbers is about the same over the ten year period, but the two-jobbers have higher initial earnings. Although job changers usually experience higher earnings growth over the decade than the loyalist, it is not enough to offset their much lower initial earnings, and so loyalists end the period with substantially higher earnings. The legendary job hoppers in the Silicon Valley, i.e., engineers who leave a good job for an even better one, are a smaller group than the job changers shown here, who are leaving relatively low-wage jobs for better jobs.

These patterns are consistent with the way big semiconductor companies changed their employment practices to increase flexibility, especially to reduce head count during downturns. The era of lifetime jobs with career development is over; most workers must use mobility to improve their job prospects.

IBM provides a good example of how downsizing programs evolved over the 1980s into the 1990s. In 1983, IBM offered workers at five locations a voluntary early retirement program in which workers with 25 or more years experience would receive two years of pay over four years. IBM offered voluntary retirement programs again in 1986 and 1989.[20] Because these programs were voluntary for the general workforce,

[19] The career paths are shown for modal groups, i.e., the largest groups of workers who have one, two, or three jobs, with at least one job in a semiconductor establishment during the decade. For those with two jobs, the modal group had a first job outside the semiconductor industry and the second job in it. For those with three jobs, the first two are outside semiconductors, and the last one in the industry.

[20] http://www.allianceibm.org/news/jobactions.htm

rather than for targeted job titles or divisions, the change in workforce usually did not turn out to be what the companies might have chosen: the better workers often opt to leave, and the weaker workers, without good job opportunities elsewhere, might stay.

The deep recession in the early 1990s finally pushed IBM, DEC, and Motorola, once known for their employment security, to make layoffs.[21] The new approach to downsizing included voluntary programs for *targeted* workers. If workers did not accept the termination program, they could become subject to layoff, making the program less than voluntary. In 1991 and 1992, IBM selected workers eligible for termination, which included a bonus of up to a year's salary. Over 40,000 workers were "transitioned" out. Downsizing continued through 1993, and by 1994 actual layoffs were occurring at IBM.[22]

With the dot.com bust in the early 2000s, massive rounds of layoffs by semiconductor companies occurred again. By the end of 2001, Motorola had laid off over 48,000 workers from its 2000 peak of 150,000 employees.[23] The volatile swings in demand meant that the idea of lifetime employment in the semiconductor industry was a thing of the past, although selected workers still had excellent job ladders with long careers.

Now we turn to look at three environmental forces that exert a large impact on the demand and supply for semiconductor engineers—technological change, graduate education practices, and H-1B visa policy.

Technological Change: Wafer Size.

Engineering jobs in chip fabs have evolved with the technology, which has simultaneously increased wafer size and automation.

Here we look at how engineering work within the fab changed across the transition from 150mm to 200mm wafers, based upon detailed data gathered in the mid-90s by the Berkeley CSM Program at a sample of fabs in four countries.[24]

New technology that accompanies a larger wafer size includes re-engineering the equipment and process technology. In addition, materials handling and information systems become highly automated in order to safely handle the increased weight of each wafer and to minimize human error in handling the increasingly valuable wafers. Automation changes the composition of the workforce to include more engineers and fewer operators. In our fab sample, engineers increased from 15% to 24% and operators declined from 73% to 62% of the total workforce between the150mm and 200mm plants, even as overall employment remained at approximately 750 workers (see Table 5).

---

[21] Some of the observations about specific firms here likely reflect divisions of these large, complex firms beyond their production of semiconductors. We think that the patterns discussed reflect the impact of globalization across high-tech firms.

[22] http://www.allianceibm.org/news/jobactions.htm

[23] http://www.bizjournals.com/austin/stories/2001/12/17/daily22.html

[24] Twenty-three fabs in four countries were part of the CSM survey. For this table, the 150mm wafers fabs were matched to the 200mm wafers fabs by company, so that the company human resource policies are comparable between the two groups, which reduced the sample to fourteen.

Table 5: Work Force Composition

(Mean Headcount in Matched 150mm and 200mm Fabs)

	150mm	200mm
Operators	547 (73%)	470 (62%)
Technicians	91 (12%)	107 (14%)
Engineers	114 (15%)	181 (24%)
Total	752	758

Source: Brown and Campbell, 2001.

The shifting of jobs from operators to engineers resulted in the growth of higher paying, high-skilled jobs at the expense of lower paying, low-skilled jobs. However the earnings structures also changed across occupations, as the initial pay premium for technicians and engineers over operators increased (see Table 6). However the returns to experience, which are proxied by the ratio of maximum pay to initial pay, show that experienced engineers fared poorly as their ratio fell from 2.8 (150mm fab) to 2.0 (200mm fab), while the returns to experience remained stable for technicians (at 1.7) and for operators (at 2.6).

Table 6: Work Force Compensation

(Mean Wage or Salary in Matched 150mm and 200mm Fabs)

	150mm		200mm	
	Initial pay	Maximum pay	Initial pay	Maximum pay
Operators (hourly)	$5.88	$15.47	$7.12	$18.44
Technicians (hourly)	$6.68	$11.50	$9.12	$15.83
Engineers (monthly)	$1,785	$5,019	$2,381	$4,689

Source: Brown and Campbell, 2001.

Experienced fab engineers were losing out over time as their average maximum real salary was actually lower in the 200mm fabs compared to the 150mm fabs. In interviews, we learned that fabs liked having young engineers with knowledge of new technology, and they did not worry about losing older engineers. Over time, consequently, fabs were willing to increase wages of new hires without raising the wages of experienced engineers. Rapidly changing technology plus an ample supply of new hires and low turnover allowed the companies to flatten engineers' career ladders with no adverse consequences, which is consistent with the ACS career paths in 2005 that showed low returns to experience for engineers after age 30. The value of experience declined with rapid technological change.

U.S.Engineering Graduate Education: Foreign Students

Graduate education has played an important role in the development of talent for the U.S. semiconductor industry, and foreign nationals play an important role in U.S.

graduate engineering programs, where they were 60% of doctoral students and 50% of master's students during 2000-2005.[25] Enrollment of foreign graduate students in engineering programs almost doubled from 1985 to 2003 when 60,000 were enrolled. In computer science, enrollment of foreign graduate students rose dramatically from 7,500 in 1985 to 24,000 in 2003.[26] Only slightly more foreign national students have been enrolled in Master's programs than PhD programs in US engineering schools since the mid-1980s, and the numbers in both programs rose steadily before stabilizing in the 1990s and rising again in the late 1990s until 2001, when the number in the Master's program began to fall after 9-11 because of increased difficultyobtaining visas. However the number of foreign nationals in the PhD program continued to rise, and by 2004 more foreign students were enrolled in engineering PhD programs than Master's programs.[27]

The highest level of engineering education, the PhD, provides engineers with state-of-the-art knowledge plus the ability to conduct research and to stay abreast of the latest technology during their careers. Here we look at which countries are sending students to engineering PhD programs in the U.S., since engineers with doctoral degrees (especially in EE) provide leadership in the semiconductor industry, from managing projects to running companies.

Figure 3 shows the annual engineering PhDs (not including computer science) awarded at U.S. universities to students from five key Asian countries over a 12-year period. In 2005, students from these five countries received 42% of the engineering PhDs awarded to non-citizens, who in turn received 64% of engineering PhDs.

The figure makes clear that Chinese students received a large and growing number of engineering PhDs. At the other extreme, Japanese students received few PhDs in the US during the period, and Japanese engineers obtained graduate training at home through programs set up by their companies with Japanese universities. Indian students received a growing number of PhD in the 1990s, and in 1997 received almost as many PhDs as Chinese students. However the number of Indian engineers granted PhDs then fell for several years before turning up again beginning in 2003.

Taiwan, which relied on U.S. PhDs to develop its semiconductor industry during the 1980s, began sending many fewer students to the US during the 1990s as university programs and job opportunities improved at home. The number of U.S. PhDs awarded to Taiwanese students declined dramatically since the mid-1990s, and Taiwanese experts in the semiconductor field have worried about the impact this might have on the supply of engineers in the forefront of semiconductor technology, since Taiwan graduate education in engineering is not as advanced as in the U.S. Korean students also received decreasing numbers of PhDs through the late 1990s, although the numbers started to increase beginning in 2002.

If we compare the number of U.S. and non-citizen PhD graduates in electrical engineering, we see that non-citizens garnered significantly more diplomas than U.S. citizens during the decade ending in 2005, and most PhDs went to men (see Figure 4). The year 1999 seems to be a turning point, when the number of PhDs to non-citizen males began to rise sharply as the number to citizen males fell. The same data for

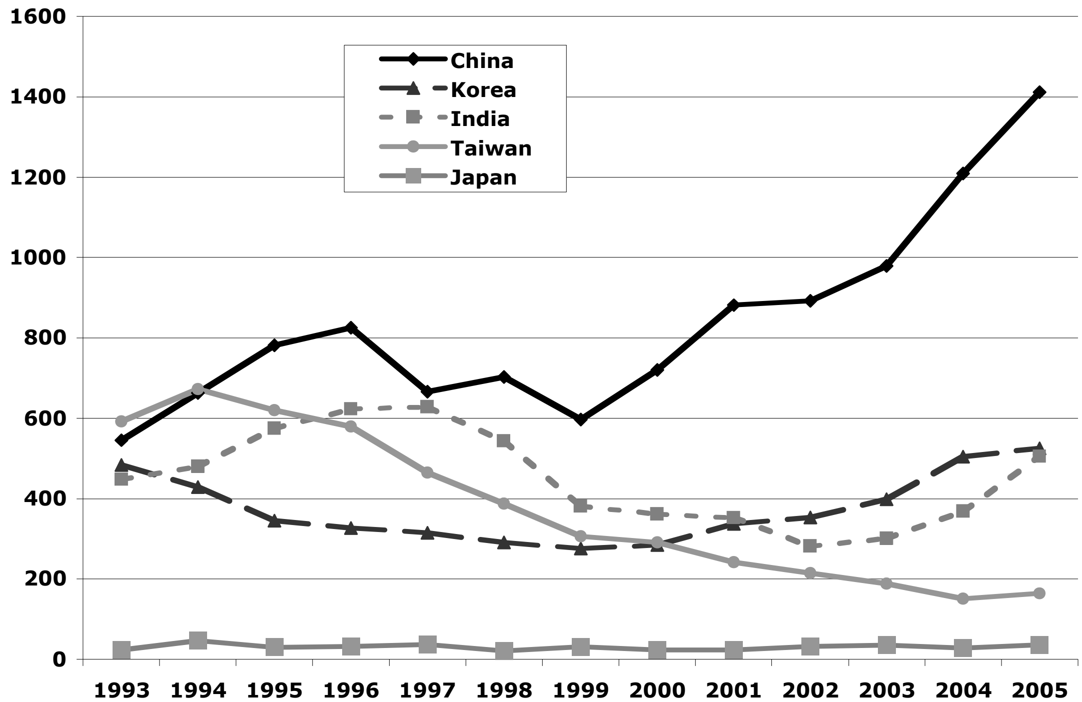
[25] See Engineering Trends, Report 1005B, October 2005, online at http://www.engtrends.com/IEE/1005B.php

[26] National Science Foundation, Science and Engineering Indicators 2006, online at http://www.nsf.gov/statistics/seind06/c2/fig02-05.htm, with link to source data.

[27] Engineering Trends, Report, op cit.

computer science PhDs shows similar but muted trends with less difference between citizens and non-citizens (Figure 5), and with many fewer PhDs awarded in CS than in EE.

Figure 3: Engineering PhDs in the US by Country of Origin, 1993-2005



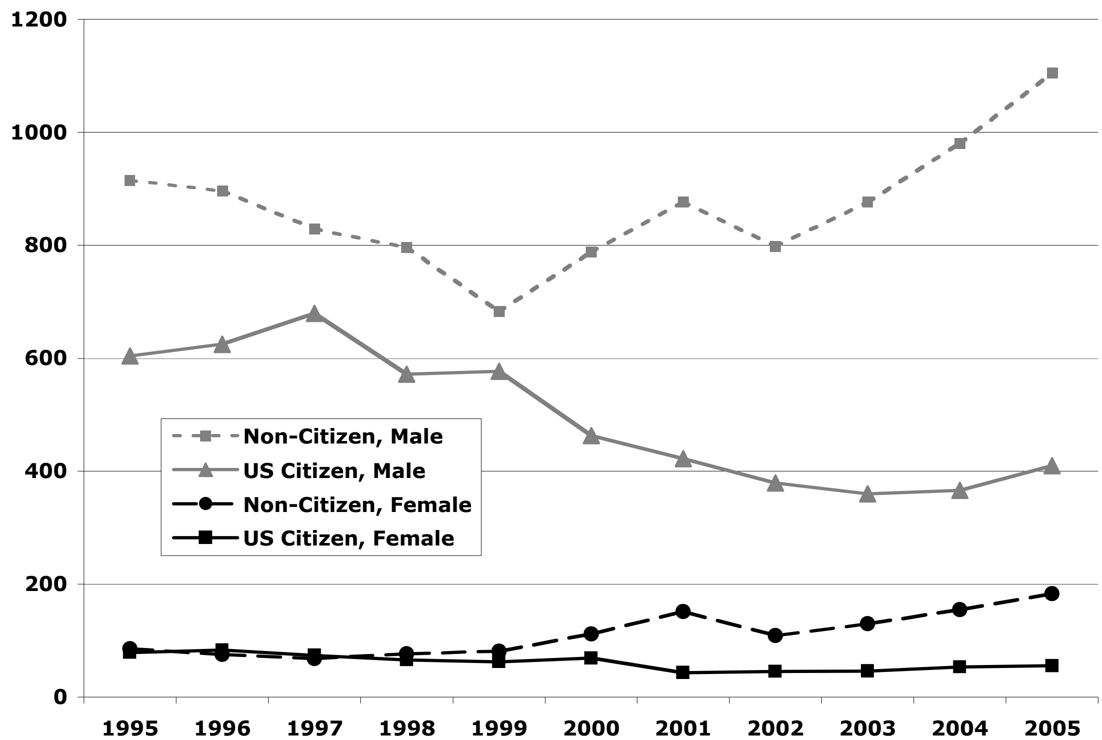
Source: National Science Foundation, Division of Science Resources Statistics, *Science and Engineering Doctorate Awards*: 2002 (App.Table 5), 2003 (App Table 11), 2004 (App Table 11), 2005 (App Table 11).

Graduate students enter the PhD program four to five years before the year the students receive their PhDs, which is shown here. A sharp increase in foreign graduate students began in the early-1990s just as the PC, and then the Internet were taking off with job opportunities for engineers with BS degrees expanding rapidly and the return to graduate training for U.S. citizens declining.

The earlier discussion of the returns to education noted that the premium for a BS in EE to pursue a graduate degree was low for domestic students. For foreign-born engineers with a BS in EEs, the financial incentive to pursue a U.S. graduate degree is much greater, since a U.S. graduate degree opens the door to high-paid jobs both in the U.S. and at home. Our fieldwork found that advanced degree holders, especially with some U.S. work experience, in semiconductor centers like Shanghai or Bangalore where they are project managers (and higher) are often paid similarly to their U.S. counterparts while locally-educated engineers are paid much less.

The wisdom of attracting bright hard-working students from abroad to graduate programs in the U.S. depends partly on whether these students stay and contribute their talents to the United States economy or they return home, where they might still work for U.S. companies or help build networks that favor U.S. relationships. The NSF surveys graduating PhD engineers about their plans to work in the U.S. or abroad, and only about 60% of the foreign engineers had plans (including a post-doc, industry job, or academic appointment) when surveyed in 2005; 82% of those who had plans that involved remaining in the U.S. For new CS PhDs, two-thirds had plans, and of those, 83% were in the U.S. Unfortunately no on-going survey tracks what happens to these highly-educated foreigners in the years after graduation, and so we do not know how long they remain in the United States. However we observe high-profile foreign engineers who were trained in the United States and then go on to executive positions, often as founders, in U.S. companies or go on to executive positions, including founders, of companies in their home countries.[28]

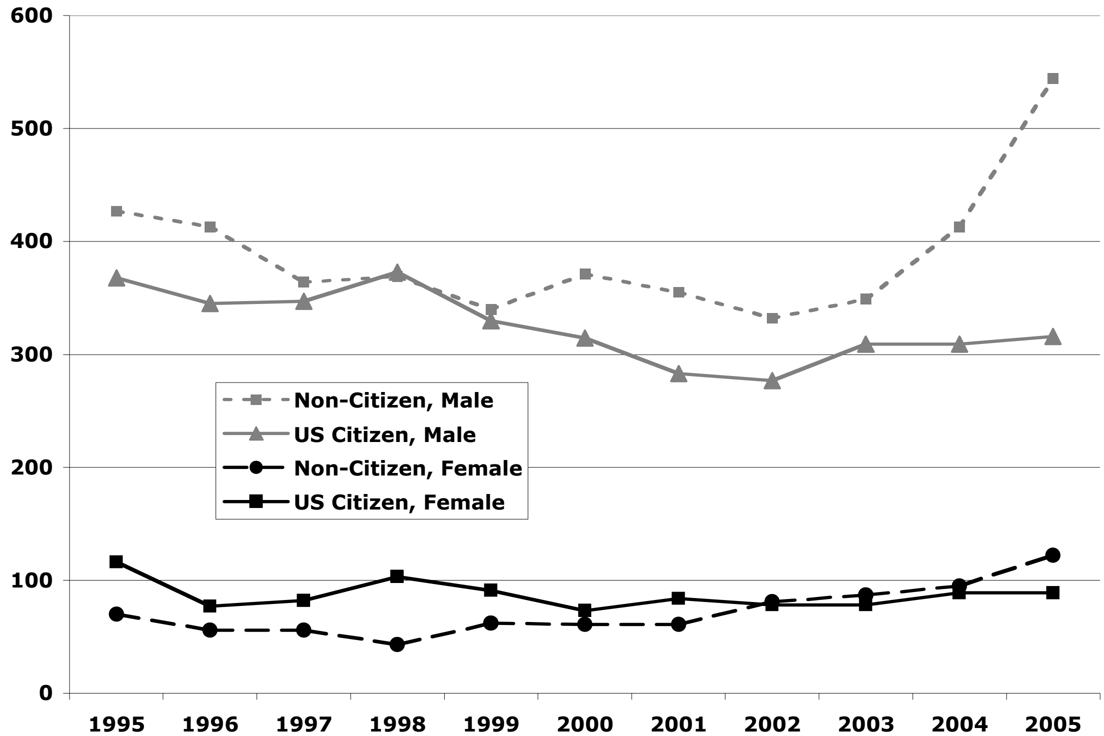
Figure 4: Electrical Engineering PhDs by Gender and Citizenship Status, 1995–2005



Source: National Science Foundation, Division of Science Resources Statistics, *Science and Engineering Doctorate Awards*: 2004 (App.Table 3), 2005 (App Table 3).

[28] AnnaLee Saxenian, *The Argonauts*, documents the process of foreign-born, US-educated engineers who return home to Taiwan, China, and India to start new companies. (Harvard U Press, 2006)

Figure 5: Computer Science PhDs by Gender and Citizenship Status, 1995–2005



Source: National Science Foundation, Division of Science Resources Statistics, *Science and Engineering Doctorate Awards*: 2004 (App.Table 3), 2005 (App Table 3).

H-1B Visas[29]

U.S. visa and educational policies directly impact the supply of engineers, especially those with advanced degrees, to the domestic market. The H-1B visa program is highly controversial, with companies lobbying hard to increase the number of visas because of a shortage of skilled workers, and with professional groups such as the IEEE-USA lobbying hard for better oversight of the program and against increasing the cap because of the harm caused to domestic engineers. Here we evaluate these competing claims by analyzing the employment and earnings of H-1B visa holders over the 2001 to 2005 period

The H-1B is a visa used by a foreigner employed temporarily in a job that requires specialized knowledge and a bachelor or graduate degree. H-1B visas are granted to companies (rather than workers) through a process that requires the company to submit an application with a job title, location, and intended wage rate or earnings at least as high as the prevailing wage. Once hired, the foreigner submits the certified application to obtain an H-1B visa. H-1B employees can work only for the sponsoring U.S. employer, and only in the activities described in the application.[30] A foreigner can work for a maximum of six continuous years on an H-1B visa (including one extension).

[29] This section draws from Brown and Linden (2006 NAE paper), which provides detailed data on the salaries of H-1B visa holders at semiconductor companies.
[30] The U.S. employer may place the H-1B visa worker with another employer if certain rules are followed. GAO (2003) http://www.gao.gov/new.items/d03883.pdf

With application fees and legal expenses, the initial cost to an employer ranges from $2,500 to $8,000 per application. H-1Bs are granted to a wide array of occupations, including those in engineering, medicine, law, social sciences, education, business specialties, and the arts.

The current law limits the number of certified H-1B visas to 65,000 annually, although the limits were temporarily raised to 195,000 in October 2000 through September 2003 in response to business lobbying.[31] However the actual number of H-1B visas granted is much higher, since only initial applications are included in the annual limitation (requests for extensions are not included), applications by universities and nonprofit research institutions are not counted against the cap, and an additional 20,000 H-1B visas for foreigners with Master and PhD degrees from U.S. universities are allowed. Unfortunately the data on the H-1B visas actually granted are not available.[32]

We analyzed data from the H-1B applications certified to the top ten U.S. chip vendors during fiscal years 2001 through 2005 to see how H-1B visa holders were faring.[33] The ten U.S. companies had 14,035 H-1B visa applications certified during the five years. Two occupation groups represent most of their semiconductor applications: electrical engineering (37% with average pay $77,560 or average minimum pay $66,944) and computer science (52% with average rate $78,537 or average minimum pay $75,685).[34] The high computer science range minimum indicates that software programmers in the chip industry are receiving a premium, which is consistent with the national earnings distributions in Table 1

We examined the applications by all other companies (called "other firms" here) for EE and CS jobs in 2005 in order to see if they used comparable rates and ranges, since H-1B visas might be functioning differently in different industries. The top chip companies accounted for 56% of all EE applications and only 5% of all CS applications. Interestingly the "other firms" mostly specified an earnings rate in their H-1B applications for both EE and CS jobs. The rates used on EE applications by "other firms" have a lower mean and 10th percentile compared to the top chip firms; the rates used on CS applications by "other firms" have a considerably lower distribution compared to the top chip firms. Again consistent with the OES data, the H-1B applications for EE-CS jobs in the chip industry appear to carry a premium compared to other industries.

We know that firms paid EE-CS engineers $66,000 to $84,000 (overall average $74,000) during 2000 to 2005 (OES national data), which seems to be below the rates on

[31] http://www.uscis.gov/graphics/howdoi/h1b.htm

[32] Even in 2003, before these exemptions for U.S. graduates with advanced degrees were implemented, many H-1B visa holders had advanced degrees. USCIS Report, "Characteristics of Specialty Occupations Workers (H-1B): Fiscal Year 2003"
http://www.uscis.gov/graphics/aboutus/repsstudies/h1b/FY03H1BFnlCharRprt.pdf

[33] On the application, companies can provide either a specific proposed pay rate or the minimum and maximum of the proposed pay range, and the top 10 companies were equally divided between those stating a specific salary rate and those stating a minimum-maximum salary range. Source: U.S. Department of Labor: http://www.flcdatacenter.com/CaseH1B.aspx

[34] The other applications were primarily for other engineering jobs (8% with average pay $79,806, or average minimum pay $65,425). We also examined data on the top ten non-U.S. chip companies for comparison. However foreign companies are more likely to use a L-1 visa (intra-company transfer) to bring in employees who have worked for the company abroad. The ten non-U.S. firms had only 1749 H-1B certifications during the period. Compared to U.S. firms, more of the applications by non-U.S firms were for business and support jobs (15%) or for non-EECS engineering jobs (18%), and the applications were more likely to state an earnings rate (80%). Compared to U.S. companies, the earnings stated by the non-U.S. companies for EE and CS applications tended to be slightly higher on average with a larger 90/10 ratio, and to be lower on average for the non-EECS jobs with a larger 90/10 ratio.

the top U.S. firms' H-1B applications. However these earnings comparisons are not for engineers with similar experience and education, since the national data includes engineers with all education levels, and the H-1B visa holders must have at least a college degree and one-half had a graduate degree in 2003[35]. In general, U.S. engineers as a group have less graduate training and more experience than engineers with H-1B visas. Many semiconductor companies hired their H-1B visa workers as graduating engineers with advanced degrees from U.S. universities, and in our fieldwork, the foreign-born and national engineers were not distinguishable at the U.S. companies, which treated them basically the same.

A government study[36] that compares EEs with H-1B visas and with U.S. citizenship in 2002 shows that the H-1Bs are younger (32 years vs 41 years; 62% under 35 years old vs 28%) and much more likely to have graduate degrees (50% vs 20%). When median annual salary of EEs aged 31 to 50 years old are compared, H-1Bs earned less than citizens: H-1Bs with graduate degrees earned $77,000, and citizens earned $88,000; H-1Bs with less than a graduate degree earned $65,000, and citizens earned $70,000. For younger EEs (aged 18-30) without a graduate degree, however, H-1Bs earned more than citizens ($60,000 vs $52,000). These data indicate that H-1B visa holders may be having a downward impact on the earnings of mature engineers, but probably not on young engineering college graduates, which is consistent with the fab-level data and national data that indicate many older engineers lack good job opportunities.

<u>H-1B Visa applications for Top Three Users.</u>

To understand how U.S. companies are using H-1B visas in their hiring, we examined the H-1B visa applications in greater detail for the top three visa users in our sample of U.S. Top 10—IBM, Intel, and Motorola—over the five year period 2001-2005.[37]

IBM, the top user of H-1B visas in our sample, received 3994 H-1B visa certifications during the five years. IBM's average minimum pay ($82,072) was considerably higher than the average minimum of the other companies. Since IBM has become more of a services company then a hardware company, we assume that many of these jobs are not chip-related.

Intel received 2,696 H-1B visa certifications, and Intel's average pay and average minimum pay were close to the averages for the top 10 U.S. companies. Intel applied for H-1B visas to fill jobs that varied across skill and experience, and overall their rates seemed to reflect national EE-CS salaries.

Motorola received 2520 H-1B visa certifications, and the average minimum-earnings were 4% below the top-10 average. Even so, the Motorola rates seem to be slightly higher than national EE-CS salaries.

The H-1B visas granted to these three companies jumped in 2004 and remained high, even as the national H-1B limitation dropped dramatically. The semiconductor

[35] In 2003, H-1B visa holders had the following advanced degrees: MS 29%, PhD 14%, Prof degree 6%. USCIS Report, "Characteristics of Specialty Occupations Workers (H-1B): Fiscal Year 2003"

[36] The GAO (2003) study of H-1B visa holders compared the annual pay for a selected group of occupations, including electrical/electronic engineers (called EEs), to a sample of U.S. workers using the Census Department's Current Population Survey in 2002.

[37] Motorola spun off its chip operations as an independent company, Freescale, in 2004, and we include the applications made by Freescale with Motorola's applications.

companies seemed to be using the additional 20,000 H-1Bs available for foreigners with a graduate degree from U.S. universities that went into effect in 2004. Over the five year period, approximately 60% of the H-1B visas awarded to the top-10 companies were awarded during the 2004-05.

Intel's H-1B visa policy appears to have shifted dramatically during the five year period. Intel increased its use of H-1B visas: a quarter of the H-1Bs were granted in the first three years and three-quarters in the last two years.

How important are H-1B visas to the companies in their hiring? In 2005, Intel employed approximately 99,900 people worldwide with more than 50% located in the U.S. Motorola employed 69,000 employees with 35% eligible for stock options, which indicates the number of non-temporary professional employees in the U.S. IBM employed 329,000 worldwide, and approximately 40% were eligible for the U.S. retirement plan (at end of 2004, when the plan was discontinued).[38]

We roughly estimate[39] that in 2005, 2.6% of Intel's domestic employees were newly-hired H-1B visa holders and 5.4% of Intel's domestic employees (and of course an even larger percentage of their engineers) were H-1B visa holders. Almost 3% of Motorola's domestic professionals were newly-hired H-1B visa holders, and 8% of Motorola's domestic professionals were H-1B visa holders in 2005. Almost 1% of IBM's domestic workforce was newly-hired H-1B visa holders, and 2.8% of their domestic workforce were H-1B visa holders in 2005.

The earnings listed on the H-1B applications made by the top-10 U.S. companies indicate that some of the H-1B visas were for high-level jobs that paid well over $100,000, as well as for low-level jobs that paid well under $50,000. These data indicate that semiconductor companies use H-1B visas strategically in hiring and managing their engineering talent. Since we cannot answer definitively if the lower-paying jobs are being used to keep semiconductor earnings low for domestic new hires, or if the higher-paying jobs are going to foreigners at the expense of qualified experienced U.S. engineers, the debate over impact of the H-1B visa program on the semiconductor labor market will continue without a winner. However our analysis indicates that the focus needs to be on the labor market problems faced by mature engineers, as well as on the graduate engineering training provided by U.S. universities to many foreign nationals, who upon graduation are in great demand by U.S. companies.

Outlook for U.S. Engineers and Their Employers

The national job market for U.S. semiconductor engineers shows some strength in employment and earnings growth, but evidence of labor market problems exist, especially for older engineers and for the bottom 10 percent across all education groups. We also observed a low premium for a graduate degrees (MS/PhD compared to a BS), so domestic students face weak financial incentives to pursue graduate degrees. However foreign students from developing countries face large premiums and incentives to come to the U.S. for graduate training.

[38] These employment figures are from the company's 10-K reports: Intel at http://finance.yahoo.com/q/sec?s=INTC, Motorola at http://finance.yahoo.com/q/sec?s=MOT, and IBM at http://finance.yahoo.com/q/sec?s=IBM.

[39] These estimates assume that these three companies used the granted H-1B visas to hire new domestic workers in 2005, and H-1B visa holders worked for five years.

The labor market situation is especially difficult for older engineers, who face rapid skill obsolescence. In general, after a few years of working, experience becomes less valuable to employers than knowledge of new technology, and engineers face stagnant and even lower earnings as they age. We saw in our fieldwork that experienced engineers are often forced to work on mature technologies with stagnant earnings, rather than being allowed to learn and work on new technologies with rising earnings.

This issue is complex because U.S. companies tend to want newly-minted graduate engineers, who have state-of-the art knowledge, to work on projects for five to seven years. Then companies select and train engineers who have leadership potential to become program managers and higher level managers. This bifurcation creates a group of engineers who move into the managerial ranks and another group who see deteriorating job opportunities as they age. When companies claim they face a shortage of engineers, they usually mean that they face a shortage of young, relatively inexpensive engineers with the latest skills, even when they have a queue of experienced engineers who want retraining.

American engineers can and are responding to the impact that the global labor market and rapidly depreciating skills are having upon their careers. The highly-rewarded career path of working for one company for one's entire adult life is no longer an option for most engineers, who can expect to work for many firms. In fact, changing jobs is now how U.S. engineers develop their careers, both in terms of improving pay and in learning new technologies and skills. Networking with colleagues from one's alma mater and former companies as well as through professional associations provides a way to keep up with knowledge about job opportunities as well as new technologies. Today's engineers must be in charge of their careers; they can no longer depend upon the employer to provide them with the continual training they need to keep up their skills. (footnote: Brown & Campbell; Cappelli; Saxenian)

In general, the well-educated semiconductor engineers who are employed worldwide by multinational companies (or high-tech start-ups) are known for their flexibility and ability to solve challenging problems and learn new technologies, and they take it for granted that the semiconductor industry is in continual crisis and change. Chip engineers even use these industry characteristics to their advantage in planning their careers by seeking jobs where they can learn about new technologies and new markets. What is new for the engineers and companies is both the quickly expanding market demand in developing countries, especially China and India because of their potentially large domestic markets, and the quickly expanding global supply of elite engineers from a variety of countries. Both the supply of and demand for engineers with leading-edge knowledge have become more mobile and more global, and the impact on the U.S. engineering market is still unfolding.

This chapter shows that foreign-born engineers account for over one-half of engineering graduate students at U.S. universities, and U.S. companies must obtain H-1B visa certifications in order to hire the foreign nationals as they graduate. We do not believe that these foreign graduates are displacing U.S. graduates in the job market. Instead, we see it more as a case of foreign students displacing potential U.S. engineering graduate students because they face a better return to education. The U.S. students may enter the engineering field with a BS, or pursue graduate degrees in different fields, such as business or law. Large number of foreign students from India and China, who are receiving high returns to graduate training compared to their opportunities with a BS degree in their home countries, have lower wage demands than their domestic colleagues, and they put downward pressure on the earnings of all engineers with MS and PhD degrees over time.

The low returns to graduate training for domestic students and the large number of foreign engineering graduate students are related and reinforcing, since a steady supply of foreign-born graduate students, who become a steady supply of well-trained new hires to U.S. companies, affects the long-run earnings of U.S.-born engineers with advanced degrees. Facing low returns to graduate training, domestic students enter the labor market with a BS degree or turn to other types of professional training, such as business or law, and foreign nationals increase their share of graduate engineering slots. With fewer foreign graduate students, we would expect that eventually domestic students would be enticed to enter graduate engineering programs as earnings for MS and PhD graduates increased, much to the consternation of U.S. companies who are hiring them.

In the absence of information on the counterfactual, we do not know how the career paths of domestic engineers would evolve over time with fewer foreign engineering students (and workers), and more domestic engineering students (and workers). The improved career paths could entail higher returns to education (entry wages) and higher returns to experience (wage growth), or both. We expect that skill depreciation and obsolescence will remain a problem for semiconductor engineers, and their returns to experience will depend upon their access to learning new technologies either at the current job or at a new one.

These outcomes are largely driven by U.S. policies that provide fellowships and funding for graduate training and that regulate immigration of students and workers. The separate discussions about the policies that regulate and finance students and those that regulate immigration have not been integrated. Recently the relationship between the two policy areas has become more transparent, as a group of H-1B visas were created for students with advanced degrees from U.S. universities. However separate debates remain focused on how many work-related visas to grant and on how many graduate fellowships to award. Instead we need a more holistic discussion that links the funding for foreign engineering graduate students to immigration policies for foreign engineers with advanced U.S. degrees, and then looks at how these policies affect the job opportunities and returns to education for domestic engineering students. Foreign-born engineering students and workers are an important part of the high-tech sector, and have made major contributions as employees and executives.

Does it matter to the U.S. if our graduate engineers are citizens or foreign nationals? Our answer is "No, as long as the foreign graduates are able to obtain jobs with U.S. companies upon graduation, and as long as they tend to remain in the U.S."

So far foreign-born engineers who come to the U.S. for graduate education have tended to remain in the U.S. However if permanent visas remain difficult to obtain, and if opportunities in home countries continue to improve, U.S. companies face an increasingly uncertain supply of graduate-trained foreign-born engineers, who currently are the backbone of the engineering workforce.

We agree with those who urge that foreign nationals in U.S. graduate programs in engineering and science become eligible for permanent residency upon graduation. Currently, for many foreign workers, the processing time to receive a "green card" (i.e., permanent residency) is longer than the six-year duration of temporary H-1B visas. Then, without legal means to remain at work in the U.S., engineers with graduate degrees from U.S. universities face the prospect of being forced to return to their home countries.

Opponents of the visa programs, especially the temporary H-1B visas, claim that the steady stream of young foreign-born engineers allow employers to hire new talent instead of retraining experienced engineers as technical knowledge deteriorates. We think that the controversy over H-1B visas needs to separate the foreign-born who are graduates of U.S. universities from the foreign-born who are educated abroad before entering the U.S. to work. Clearly foreign-born engineers with graduate U.S. degrees should be encouraged to work in the U.S., and for a number of years sufficient to allow becoming a permanent resident.

The U.S. has benefited enormously from the global brain circulation, as our graduate engineering programs have attracted some of the "best and brightest" from China and India and abroad. They have remained in the U.S. to start companies and to work in established U.S. companies both here and in their home countries. The issue is the degree to which our dependence upon foreign graduate students may make our supply of new graduates vulnerable over time as job opportunities in their home countries improve. This should be the focus of the policy debates on higher education and visas for foreign-born engineers.