# Recruitment of Foreigners in the Market for Computer Scientists in the US

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October, 2012

**Very Preliminary Version** - Please do not cite, comments welcome

**Abstract**

The H-1B visa program remains controversial. Advocates, including leaders in the IT industry, have argued the need to relax current quotas, claiming that there are simply not enough skilled workers in the US to satisfy demand. On the other hand, others have argued that the H-1B visas program benefits IT employers, at the expense of the wages and employment prospects of IT workers. In this paper, we explore the impact that the H-1B program had on the labor market for computer scientists in the U.S. during the Internet boom of the 1990s, a period of time that saw the dramatic growth in the number of foreign born computer scientists working in the U.S. on H-1B visas. To asses the impact of the dramatic expansion of the number of foreign born computer scientists working in the U.S. during the 1990s we follow two strategies. The first compares employment and wage outcomes during the IT boom associated with the introduction of the PC in the late 1970s, to the more recent one. As an alternative strategy, we build a dynamic model of the labor market

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for computer scientists, benchmarking the model with available US data. We find a greater wage and smaller total employment response during the earlier boom, consistent with the notion that the availability of foreign high skilled workers has increased the overall labor supply elasticity of skilled workers to the US IT sector. Using our model to evaluate counter-factuals, we simulate that had US firms not been able to increase their employment of foreign computer scientists over their 1994 levels, they would have succeeded in replacing about half of the shortfall with US residents and the earnings of computer scientists would have increased by about 50% more than they actually did.

## 1 Introduction

How the supply of workers well-qualified for science and engineering (S&E) employment in the U.S. adjusts to changes in demand from industry and research funding is often viewed as central to continued economic growth and innovation in the U.S. economy. Our research focuses on the pathways of labor market adjustment in S&E occupations and the roles of changes in immigration and post-secondary educational attainment.

We study these adjustment mechanisms and incorporate them in an economic model of the S&E workforce. Our research questions are twofold:

1. How do different channels of adjustment including immigration and associated visa policies, post-secondary education attainment and mobility among occupations contribute to participation in the U.S. S&E workforce?

2. What economic models explain the observed pathways of adjustment and labor market outcomes in employment and wages?

In addressing these questions, our research emphasizes the significance of the link between immigration and the labor market. The flow of foreign-born to the U.S. S&E labor market is a reflection of both basic economic incentives and policies governing visas and immigration. To the extent that the U.S. economy offers better opportunities for high-skill workers than developing or emerging economies, there is a natural incentive to immigrate. Immigration policy and the flow of foreign-born workers to the U.S. may impact employment, wages, and innovation in the economy.

An issue is whether immigrants either "crowd out" natives from computer science jobs or put downward pressure on their wages. Kerr and Lincoln (2010) and Hunt and Gauthier-Loiselle (2010) provide original empirical evidence on the link between variation in immigrant flows and innovation measured by patenting, finding evidence suggesting that the net impact of immigration is positive rather than simply substituting for native outcomes. Kerr and Lincoln (2010) also show that variation in immigrant flows at the local level related to changes in H-1B flows do not appear to adversely impact native employment and have a small, statistically insignificant effect in their wages. A challenge in this kind of framework is that the observed, reduced-form outcome may capture concurrent changes in area specific demand for computer scientists. In the context of an economic model, it is difficult to generate a situation in which there is little crowd out unless demand is very elastic (Kerr and Lincoln's point estimates reported in table 2 suggest a demand elasticity of $0.062/0.010 = 6.2$). There are models of the labor market which could rationalize such large elasticities[1]. Alternatively Kerr and Lincoln's results can be interpreted within the context of a model of the labor market for IT workers in which firms face a less than perfectly elastic supply schedule of US trained workers. In the context of such a model, when employers face costs to hire immigrant labor and are bound to pay the going wage, firms hire immigrants only when the demand for workers is increasing dramatically. Immigrants do not replace incumbent workers in this case, but have a negative impact on the growth of wages and employment for natives.

To focus our study, we examine the market for computer scientists in the US during the Internet boom in the 1990's, during which this labor market adjusted significantly. In the 1990's, the number of H-1B visa high-skilled immigrants increased substantially, both overall and in this sector, as did enrollment in computer science degrees and employment as computer scientists. Within this specific sub-sector of S&E employment, workers switching from other related occupations are an important component of how the market adjusts. We compare the Internet boom to a similar boom

[1]If, for example, absent the foreign workers, IT firms outsourced computer science jobs, the demand elasticity could be infinite as is true in the Hecksher-Ohlin model.

for computer scientists starting in the mid-1970's with the introduction of the personal computer, during a period of time when immigrants were far less significant component of the labor market for computer scientists. To model this market and to construct counterfactual simulations of interest, we propose a dynamic structural model that includes the three main sources of workers entering the market for computer scientists:

1. New college graduates
2. Immigrants
3. Occupation switchers

Our model can be seen as a generalization of earlier models of the market for scientists and engineers (Freeman (1975, 1976); Ryoo and Rosen (2004)). As in their models, we start by modeling the decisions students make about fields of study, but we also go on to model workers' employment sector choices with a discrete-choice framework similar to the one developed by Kline (2008), including occupational switching costs, hiring adjustment costs and varied individual taste for working as a computer scientist. Employers can choose to hire U.S. or foreign workers. Hiring foreigners involves an extra cost, whereas hiring US workers will serve to drive up their wages.

The supply side of our model is reasonably standard. The demand side is less so. We model the representative firm as facing an upward sloping supply curve of labor. It is thus a monopsonist. How reasonable this is, we are not sure. Embedded in this assumption is the notion that firms will realize that if they were to continue to hire American workers, they would bid up their wages. In the model, firms will be more likely to hire foreigners when demand is expanding rapidly and is expected to do so for a while.

Given our assumptions about the supply of computer scientists to the IT sector, the supply curve of US workers will be upward sloping, more so in the short term, and the supply curve of foreigners to the sector will be perfectly elastic. However, while this is true at the level of the sector, it will not be true at the level of the firm unless the firm has some monopsony power. The way we are currently modeling demand, the supply curve to the firm mirrors the supply curve to the sector. We realize that this is not very satisfactory and are looking for reasonable alternatives. At the same time, we doubt the qualitative conclusions we draw from our model are particularly sensitive to this assumption.

## 2 The Market for Computer Scientists in the 1990's

The market for computer scientists went through significant transformations during the 1990's. According to the Census, the number of employed individuals working as either as computer scientists or computer software developers (CS) increased by 161% between the years 1990 and 2000. As a comparison, during the same period, the total number of employed workers with at least a bachelor degree increased by 27%, while the number of workers in other STEM occupations increased by 14%[2]. There is no doubt this was a period of employment expansion for CS.

The most reasonable explanation for the considerable employment growth of CS employment is that the technological changes that happened during this period had a significant impact on the demand for computer scientists. In particular, during the mid 1990's, we observe the beginning of the utilization of the Internet for commercial purposes in the United States[3] and a substantial increase of Internet users, as presented in Figure 1. Consequently, the necessity of attending the demands of new consumers willing to spend time and money on-line made the skills of computer scientists a valuable resource in that decade.

As a matter of fact, the increase in the employment of CS happens concomitantly to the dissemination of the Internet. Evidence for this claim is presented in Figure 2, which shows the fraction of employed individuals with a bachelor degree working as computer scientists. It is clear from the figure that the substantial increase in employment of CS happened in the second half of the decade, the same period of time when the Internet became popular among American consumers. In the same way, Figure 3 presents the employment of computer scientists as a share of total STEM

[2]Authors' calculations using IPMUS Census. We restrict to workers with at least a bachelor degree and use the IPMUS suggested occupational crosswalk. Other STEM occupations are defined as engineers, mathematical and natural scientists.

[3]The decommissioning of the National Science Foundation Network in April of 1995 is considered the milestone for introducing nationwide commercial traffic on the Internet.(Leiner et al. (1997)).

employment. There one can see that there was an increase in CS employment, even compared to other scientific occupations that could also have been affected by the technological changes of the period.

In addition to the employment decision of workers, there is evidence that Internet dissemination also affected studying and educational enrollment decisions of students. In fact, the number of bachelor degrees awarded in computer science increased 77% between 1990 and 2002[4]. In order to put these numbers in perspective, we use the Integrated Postsecondary Education to Data System (IPEDS) Completion Survey to show in Figure 4 the number of bachelor degrees awarded in computer science as a fraction of both the total number of bachelor degrees and the number of STEM major degrees. It is clear from the figure that the decision to study computer science also responded to the Internet boom. The CS share of total bachelor degrees increased from about 2% in 1995 to more than 4% in 2002.

More importantly for the purpose of this paper, employment adjustments in the market of computer scientists happened disproportionately among foreigners during the Internet boom, when the non-citizen fraction of individuals working as either computer scientists or computer software developers increased from 7% to 15% between 1990 and 2000[5]. Additional evidence is found using the CPS, where we compare the foreign share of computer scientists to the foreign share of workers with other occupations. In particular, in Figure 5 we show that in the second half of 1990's the foreign fraction of CS increased considerably more than both the foreign fraction of all workers with a bachelor degree and the foreign fraction of all workers with a STEM occupation. In particular, foreigners were about equally represented among individuals working as computer scientists or in other STEM occupations in 1994. However, with the dissemination of the Internet in the later years of the decade, foreigners became a more important part of the pool of CS workers.

Furthermore, there is evidence that the main variation in foreign employment came from individuals that were trained abroad rather than foreigners that got their highest degree in the US. Evidence for this claim is presented in Figure 6, where we use the National Survey of College Grad-

[4] Author's calculation using IPEDS Completions Survey

[5] Authors' calculations using IPMUS Census. We restrict to workers with at least a bachelor degree and use the IPMUS suggested occupational crosswalk.

uates (NSCG) to estimate the number of people working as computer scientists in 1993 and 2003, distinguished by citizenship, field and location of study. In 1993 only 2.1% of CS workers were foreigners that earned their highest level education abroad while in 2003 the number increased to 7.2%[6].

Additionally, there is some institutional evidence that technology firms used temporary non-immigrant workers, such as the H-1B visa holders, to adjust their employment during the Internet boom. Numbers from the GAO (1992) report show that computers, programming, and related occupations corresponded only to 11% of the total number of H1 visas in 1991, as presented in Table 1. However, as labor demand increased, computer scientists became a more significant fraction of individuals that received these type of working visas. Specifically, Table 2 shows that the number of H-1B visas awarded to computer-related occupation in 1999 jumped to more than 50% of total visas (INS (2000) ). These numbers demonstrate that technological firms were the ones that best took advantage of the changes in immigration of high skill workers through the 1990's.

The empirical evidence is that wages of computer scientists also responded to the Internet boom. From the Census, we observe that between 1990 and 2000, the median real weekly wages of CS increased by 18%[7]. The CPS presents similar patterns: starting in the year 1994 we observe in Figure 7 that wages of computer scientists increased considerably when compared to both other workers with other STEM occupations and all workers with a bachelor degree. In fact, while during the beginning of the 1990's, the earnings of CS were systematically lower than other STEM occupations, the wage differential tends to disappear after 1998.

We have presented evidence that the Internet innovation had a positive impact on both employment and wages of computer scientists during the period. The question is, how would the labor market for CS have adjusted if firms could not hire foreigners. How much higher would the earnings of computer scientists have been? How much smaller would the computer scientist workforce have

[6]The National Surveys of College Graduates follows-up the 1990 and 2000 censuses. Individuals identified as college graduates in 1990 and then in 2000 were followed up three years later. As a result, the NSCG surveys will miss individuals who obtained their bachelor degrees between 1990 and 1993 or between 2000 and 2003. Perhaps more importantly, they surveys will miss individuals in the US in 1990 or 2000 who emigrated over the next three years.

[7]Authors' calculations using IPMUS Census. We restrict to workers with at least a bachelor degree and use the IPMUS suggested occupational crosswalk.

been? To crudely answer these questions we compare the IT boom of the 1990s to an earlier boom that occurred during the late 1970s and early 1980s associated with the introduction of the PC. During the earlier boom, foreigners represented a substantially smaller fraction of the workforce. In addition, we construct an economic model that describes the behavior of firms and workers that participate in the market for computer scientists. In particular, we calibrate the parameter of this model such that it reproduces the stylized facts we observe in the CS market during the 1990's. We use the calibrated model to simulate how an economy where firms cannot hire foreigners reacts to a technological shock.

## 2.1 Comparisons Between the Personal Computer and Internet Booms

In the previous section we described how important the dissemination of the Internet was for the market of computer scientists. However, this was not the first innovation that had a substantial impact on the information technology (IT) industry. In fact, the development of microprocessors during the 1970's led to the creation and commercialization of personal computers (PC), the expansion of the information technology industry and consequently, an increase in the demand for computer-based occupations.

There is some anecdotal evidence on how important the PC innovation was to the information technology sector in the late 70's and early 80's. For instance, during this period, we observe the foundation and early development of Microsoft Corporation and Apple Inc, two of the biggest players in the American IT industry for the next several decades. These two, along with other companies in this budding industry invested significantly in the development and popularization of PCs to the point that the computer was elected the "person" of the year in 1982 by Time magazine (Campbell-Kelly and Aspray (2004)). More concretely, the research and development (R&D) expenditure of firms in both the computer programming services and the computer and related equipment sector increased substantially between 1975 and 1985. The share of R&D of firms in these two sectors combined increased from 12% to 18% of total R&D spending by all publicly tradable firms during this period[8].

In addition to increased R&D investment, due to the PC innovation, the market value of the companies in this industry grew considerably during the late 70's and early 80's. More specifically, Figure 8 presents the variation of the NASDAQ composite, a stock market index often used as a measure of the performance of technology companies, in the past decades. The figure shows that the companies in the IT sector had two periods of increased prosperity comparatively to the overall economy: the late 70's and early 80's, defined here as the PC boom, and the late 90's, defined here as the Internet boom.

Overall, there is evidence that both PC and Internet innovation had an impact on the information technology industry. However, these two events differ substantially in terms of availability of foreigners for labor adjustments. In fact, Figure 9 uses Census data to show that non-citizens were a small fraction of computer scientists in 1970 and 1980. In precise terms, foreigners represented only 4.7% of CS workers in the US in 1980, while this share was 15.1% in 2000. Given the evident difference in terms of foreign recruitment by technological firms during the PC and Internet booms, it is of considerable interest to investigate if the labor market of computer-based workers reacted differently to these two events.

In order to make a comparison between the impact of the PC boom and the Internet boom in terms of labor market outcomes, we have to construct a series of employment and wages that are consistent over a longer period of time. This task is particularly difficult for computer scientists because the definition of their occupation and the tasks related to their job changed over time. In particular, during the early developments of the computers, there was a certain confusion of scope of work of CS and it was not until the 1980's when computer science became a well established, distinct field of study in college (Denning (2008)). Our response to those issues is to redefine the computer-based occupation of interest as a broader category when making comparisons over a long period of time. Specifically, we study both computer scientists and electrical engineers (EE) when comparing the effect of the PC and Internet innovation on labor market outcomes and studying

[8]Authors' calculations using Compustat data. The two sectors used for our analysis are computer and office equipment (SIC 357) and computer programming, data processing, and other computer related services (SIC 737).

decisions. The justification is that there is a significant overlap of the scope of work between these two occupations, especially in the early stages of the development of the IT industry.

We first compare the impact of the PC and Internet shocks on enrollment decisions of individuals. Using the IPEDS, we show in Figure 10 how the number of bachelor degree awarded in computer science and electrical engineering changed compared to both the total number of bachelor degrees and the number of STEM major degrees. In this figure, we find evidence that students responded to the PC innovation similarly to how they responded to the Internet innovation in terms of major choices. In fact, the share of degrees awarded to CS and EE is highest in the mid-1980's and early 2000's, at the end of the PC and Internet boom respectively.

Now we turn to studying labor market outcomes. Unfortunately the data we used to study the impact of the Internet boom on labor market outcomes turned to be problematic for a more extensive time frame investigation. More specifically, the Census year observation happened in 1980, which was exactly in the middle of the PC boom, making it impossible to do a before and after comparison of labor market outcomes. Furthermore, in the CPS we had sampling problems due to the low number of workers that are computer scientists and electrical engineers in the early stages of development of the information technology sector. For this reason, we use other sources of data that prove to have more consistent series of employment and wages along time in this part of the study.

In particular, for employment series we rely on both the Current Employment Statistics (CES) and the Census. From the CES, we obtain employment data for the years of 1972 to 2000, divided into 3 sectoral levels: computer and office equipment (SIC 357), computer programming, data processing, and other computer related services (SIC 737); and other private industry. From the Census, we get information on the share of computer scientists and electrical engineers working in each of these 3 sectors during the Census years of 1970, 1980, 1990, and 2000. Using a linear projection we are able to predict what this share would be in every year between 1972 and 2000. Finally, we use a variant of the fixed coefficients manpower requirements model (Freeman (1980), Katz and Murphy (1992)) to recover a proxy for the percentage change of the employment of CS and EE at time $t$, such that:

$$\%\Delta E_t = \sum_j 0.5 * (S_{jt} + S_{jt-1})(ln(emp_{jt}) - ln(emp_{jt-1}))$$

where $emp_{jt}$ is the ratio of the employment in industry $j$ to the total employment in the private industry in period $t$ and $S_{jt}$is the (projected) share of CS and EE in sector $j$, as of time $t$ for $j$= the 3 industries described above. This percentage change of the employment of CS and EE is presented in Figure 11. The figure shows that both the PC and Internet boom had an significant impact on the employment of computer scientists and electrical engineers. However, the percentage change in employment was slightly smaller in the late 1970's than it was in the late 1990's, the time period when firms recruited foreigners extensively.

Additionally, we rely on the New Entrants Survey (NES) and the National Survey of Recent College Graduates (NSRCG) for earnings information. These two surveys present detailed information on recent graduates from 1976 to 2006. In figure 12, we compare the earnings of recent graduate workers with a computer science and electrical engineering degree from the NES and NSRCG with the earnings of all workers with at least a bachelor's degree from the March CPS. From the figure, we observe that earnings of CS and EE also responded to the PC and Internet innovations in a similar way. Specifically, we see a persistent wage growth for the two occupations in the late 1970's and late 1990's, the exact same period when the two innovations were introduced. Furthermore, we observe that the earnings increase was slightly higher during the PC boom for both computer scientists and electrical engineers.

To sum up, we find evidence that the market for computer-based occupation responded in similar ways to the PC and the Internet innovations. In both, we observe an increase in earnings and employment of computer scientists and electrical engineers, with a slightly higher increase of earnings in the 1970's and a slightly higher increase of employment in the 1990's.This result is consistent with the notion that the availability of foreign high skilled workers has increased the overall labor supply elasticity of skilled workers to the US IT sector.

# 3 A Dynamic Model of Supply and Demand of Computer Scientists

The objective of this section is to construct an economic model that describes the dynamic supply and demand for computer scientists (CS) when firms are able to recruit foreigners. More specifically, the goal is to design a model that reproduces the stylized facts of this market in 1990's and enables the assessment of the importance of foreign recruitment for wages and employment during this period.

The general framework is that demand shocks in the market for computer scientists can be accommodated in three different ways. First, by Americans earning a computer science degree. These individuals must complete 4 years of college before they are ready to work. Second, by Americans in other occupations who are also able to work in CS, but must pay costs to switch occupations. Third, by foreigners that can be hired by American companies to work as computer scientists. However, there are recruitment costs to bring those workers to the US.

## 3.1 Labor Supply of American Computer Scientists

We model the supply of American computer scientists as a result of career choices of workers. In precise terms, individuals make two types of decisions along their career in order to maximize the expected present value of their life time utility. At age 18, individuals choose the field of study that influences their initial occupation after graduation and from age 22 to 65, workers choose between working as a computer scientist or in another occupation. Individuals have rational, forward looking behavior and make studying and working decisions based on the information available at each period.

The information used by individuals for their career choices is the same and shared by all. Specifically, the set of information $\Omega_t$ is:

1. The current wage of computer scientists: $w_t^c$ and the other occupation $w_t^o$.

2. The number of American workers at different ages $a$ employed as computer scientists at the

beginning of each period: $L^a_{t-1}$.

3. The number of foreign CS workers employed at beginning of each period: $F_{t-1}$.

4. The number of recent college graduates with a CS degree: $C_t$.

5. The productivity level of firms that hire CS: $A_t$.

#### 3.1.1 Studying decision

We do not have reliable data on the course of study of students, but do have such data on degrees obtained. To keep things simple and consistent with the data we have, we assume that students make course of study decisions when they enter college at the age of 18. How do students make major decisions in our model? At age 18, an individual $i$ draws idiosyncratic taste shocks for studying computer science or another field: $\eta^c_i$ and $\eta^o_i$,respectively. This student also has expectations about the prospects of starting a career in each occupation after graduation (age 22): $V^c_{22}$ and $V^o_{22}$ . With this information, an individual chooses between pursuing a computer science or a different degree.

We model the utility of a student as a linear function of the taste shocks and career prospects in each sector. There is also a taste attractiveness parameter $\alpha_o$ for studying a different field from computer science and individuals discount their future with an annual discount factor $\beta$. The field of study decision is represented by:

$$max\{\beta^4 \mathbb{E}_t V^c_{22} + \eta^c_i, \beta^4 \mathbb{E}_t V^o_{22} + \alpha_o + \eta^o_i\}$$

In the model, taste shocks have important implications for career decision of workers, but are not easily observed in the data. We assume that $\eta^c_i$ and $\eta^o_i$ are independently and identically distributed and for $s = \{c, o\}$, can be defined as $\eta^s_i = \sigma_0 v^s_i$ , where $\sigma_0$ is a scale parameter and $v^s_i$ is distributed as a standard Type I Extreme Value distribution. This distribution assumption is common to dynamic discrete choice models (Rust (1987), Kline (2008)) and it is convenient because it allows the decision of agents to be smoothed out and, as it will be clear later, has desired differentiability properties that will be used in the characterization of the equilibrium of the model.

Giving the distribution assumption of idiosyncratic taste shocks, it follows that the probability of a worker *graduating* with a computer science degree can be written in logit form:

$$p_t^c = [1 + exp(-(\beta^4 \mathbb{E}_{t-4}[V_{22}^c - V_{22}^o] - \alpha_o)/\sigma_0)]^{-1}$$

Note that the important parameter for how studying choices of workers are sensitive to different career prospects is the standard deviation of taste shocks. In fact, small values of $\sigma_0$ imply that small changes in career prospects can produce big variation in the number of students graduating with a computer science degree.

The next step to characterize the supply of young computer scientists is to map the graduating probability described above to employment. Defining $M_t^a$ as the exogenous number of college graduates with age $a$ in time period $t$, the number of recent graduates with a computer science degree in year $t$ is represented by $C_t = p_t^c M_t^{22}$. And the number of college graduates with a computer science degree will strongly influence the supply of young workers.

### 3.1.2 Working Decision

The field of study determines if an individual enters the labor market as either a computer scientist or with a different occupation. However, individuals can choose to switch occupations along their careers. Specifically, at the begging of each period, individuals between ages 22 and 65 choose to work in CS or another type of job in order to maximize the expected present value of their life time utility.

A feature of the model is that switching occupations is costly for the worker. In other words, workers pay a monetary penalty for changing to a new job in the current period from their job in the previous period. A justification for this assumption is that workers have occupational-specific human capital that cannot be transferred (Kambourov and Manovskii (2009)). For simplicity, we assume the cost to switch occupations is constant along a worker's career and it is the same for all workers changing into or out of the computer scientist occupation. Additionally, there is no general human capital accumulation and wages do not vary with the age of a worker.

Finally, we assume that workers have linear utility from wages, taste shocks and career prospects.

Furthermore, wages must be totally consumed in that same year and workers cannot save or borrow. The bellman equations of worker $i$ at age $a$ between 22 and 64 at time $t$ if he starts the period as a computer scientist or other occupation are respectively:

$$V_a^c(\Omega_t) = max\{w_t^c + \beta \mathbb{E}_t V_{a+1}^c(\Omega_{t+1}) + \varepsilon_{it}^c, w_t^o - c + \beta \mathbb{E}_t V_{a+1}^o(\Omega_{t+1}) + \varepsilon_{it}^o + \alpha_1\}$$

$$V_a^o(\Omega_t) = max\{w_t^c - c + \beta \mathbb{E}_t V_{a+1}^c(\Omega_{t+1}) + \varepsilon_{it}^c, w_t^o + \beta \mathbb{E}_t V_{a+1}^o(\Omega_{t+1}) + \varepsilon_{it}^o + \alpha_1\}$$

where $c$ is the monetary cost of switching occupation and $\alpha_1$ is the taste attractiveness parameter for not working as a computer scientist. For simplicity, we will assume that the current wage in the other occupation $w_t^o$ is exogenous and perfectly anticipated by the workers[9]. In the model, all workers retire at age 65 and their retirement benefits do not depend on their career choices. As a consequence, workers at age 65 face the same decision problem but, without consideration for the future.

As in the major decision problem, idiosyncratic taste shocks play an important role in working decisions of an individual. Once more, we will assume that taste shocks are independently[10] and identically distributed and for $s = \{c, o\}$ can be defined as $\varepsilon_{it}^s = \sigma_1 v_{it}^s$ where $\sigma_1$ is a scale parameter and $v_i^s$ is distributed as a standard Type I Extreme Value distribution.

Defining $p_{t,a}^{oO}$ as the probability of a worker at age $a$ between 22 and 64 to move from occupation $o$ to occupation $O$, it follows from the error distribution assumption that the migration probabilities can be represented as:

$$p_{t,a}^{oc} = [1 + exp(-(w_t^c - w_t^o - c - \alpha_1 + \beta \mathbb{E}_t[V_{a+1}^S(\Omega_{t+1}) - V_{a+1}^s(\Omega_{t+1})])/\sigma_1)]^{-1}$$

$$p_{t,a}^{co} = [1 + exp(-(w_t^o - w_t^c - c + \alpha_1 + \beta \mathbb{E}_t[V_{a+1}^S(\Omega_{t+1}) - V_{a+1}^s(\Omega_{t+1})])/\sigma_1)]^{-1}$$

and the migration probabilities of workers at age 65 are the same without discounting future career prospects.

[9]As matter of fact, in the simulation of the paper we will set $w_t^o = 1$ and measure of wages of computer scientists as an occupational premium.

[10]In the working decision problem, the independence assumption might be less plausible because taste shocks could be serially correlated. However, identifying parameters of the model with serially correlated errors is infeasible without longitudinal data (Kline (2008)).

Note that the switching probabilities depend upon both the current wage differential and expected future career prospects at each occupation. Furthermore, the standard deviation of the taste shocks, the sector attractiveness constant and the cost to switch occupation will be the important parameters in the determination of the supply elasticity of American computer scientists.

A feature of dynamic models with forward looking individuals is that working decisions depend upon the equilibrium distribution of career prospects. As in the dynamic choice literature with extreme value errors (Rust (1987) and Kline (2008)), we use the properties of the idiosyncratic taste shocks distribution to simplify the expressions for the expected values of career prospects. As a result the expected value function for an individual at age $a$ between 22 and 64 working as a computer scientists or in another occupation are respectively:

$$\mathbb{E}_t V^c_{a+1}(\Omega_{t+1}) =$$
$$\sigma_1 \mathbb{E}_t[\gamma + ln\{exp((w^c_{t+1} + \beta \mathbb{E}_{t+1} V^c_{a+2}(\Omega_{t+2}))/\sigma_1) + exp((w^o_{t+1} - c + \alpha_1 + \beta \mathbb{E}_{t+1} V^o_{a+2}(\Omega_{t+2}))/\sigma_1)\}]$$

$$\mathbb{E}_t V^o_{a+1}(\Omega_{t+1}) =$$
$$\sigma_1 \mathbb{E}_t[\gamma + ln\{exp((w^o_{t+1} + \alpha_1 + \beta \mathbb{E}_{t+1} V^S_{a+2}(\Omega_{t+2}))/\sigma_1) + exp((w^s_{t+1} - c + \beta \mathbb{E}_{t+1} V^S_{a+2}(\Omega_{t+2}))/\sigma_1)\}]$$

(1)

where gamma $\gamma \cong 0.577$ is the Euler's constant and the expectations are taken with respect to future taste shocks. Workers at age 65 face the same expected values but don't discount the future.

Now we turn to transforming migration probabilities to employment. The first step is to determine the CS supply of recent college graduates. After leaving college, individuals can start their career in the occupation correspondent to their field of study with no cost. However, we also allow workers at age 22 to pay the switching costs and get their first job in an occupation different from their field of study. As a consequence, the number of computer scientists at age 22 is a function of the number of recent graduates with a computer science degree and the migration probabilities:

$$L^{22}_t = (1 - p^{co}_{t,22})C_t + p^{oc}_{t,22}[M^{22}_t - C_t]$$

where $M_t^{22}$ is the number of recent college graduates, $C_t$ is the number of recent graduates with a computer science degree, and $M_t^{22} - C_t$ is the number of college graduates with any other degree.

In the same way, the supply of computer scientists at age $a$ from 23-65 is a function of past employment in each sector and the migration probabilities:

$$L_t^a = (1 - p_{t,a}^{co})L_{t-1}^{a-1} + p_{t,a}^{oc}[M_{t-1}^{a-1} - L_{t-1}^{a-1}]$$

where $M_t^a$ is the exogenous total number of workers in the economy at age $a$ in time period. $M_t^a - L_t^a$ is the number of workers at age $a$ working in the residual sector. For simplicity, we will assume that the number of workers in the economy at age $M_t^a$ is exogenous and constant over time[11].

The aggregate domestic labor supply of computer scientists is the sum of labor supply at all ages:

$$L_t = \sum_{a=22}^{a=65} L_t^a \quad (2)$$

Note that the labor supply of computer scientists depends on past employment, new college graduates with a computer science degree and on wages through the migration probabilities.

## 3.2 Labor Supply of Foreign Computer Scientists

An important characteristic of our model is that firms can recruit foreigners to work as computer scientists. As it will become clear throughout the section, this possibility has implications on how the market for CS workers responds to technological shocks, such as internet innovation, in terms of wages and American employment.

We model foreign computer scientists as having a perfect elastic labor supply. In other words, foreigners accept work as computer scientists for any wage higher than their reservation wage. We also assume that their reservation is low enough that foreigners are willing to accept work for any realized wage level of the American market for CS. Additionally, we assume that foreigners cannot

[11] In the simulation of the paper we set $M_t^a$ to be constant for all ages and such that $\sum_{a=22}^{a=65} M_t^a = 100$ . This way we measure employment of computer scientists as percentage points of the employed population of interest.

switch occupation once hired to work as computer scientists and they must stay in the US until the end of their contract.

A simplified way to model the framework describe above is to define a constant rate of separation $s$, that represents the fraction of foreigners that have their contract terminated at the end of each year. If, for example the typical contract of a foreigner is 6 years, we assume that in each year, 1/6 of foreigners have their contract terminated and the labor supply of foreigners can be represented as[12]:

$$F_t = (1-s)F_{t-1} + R_t \quad (3)$$

where $F_{t-1}$ is the number of foreign CS workers employed in the past period and $R_t$ is the number of foreign CS workers recruited in time period $t$.

## 3.3 Labor Demand for Computer Scientists

First, we assume there is only one type of firm that hires computer scientists. Furthermore, CS labor is the only input used in the production function and we ignore the firm's decision about capital or other type of labor adjustments[13]. Second, we assume that all types of computer scientists are equally productive and that Americans of all ages and foreign computer scientists are perfect substitutes for each other.

Third, all computer scientists in the market are paid the same wage independently of their age or citizenship[14]. This assumption is in accordance with the H-1B visa regulation that require that wages paid to foreigners must be at least the prevailing wage rate for the occupational classification in their area of employment. Finally, firms incur extra costs to recruit foreigners. This expenditure is justified by the fees and expenses directly related to the visa application process, and also the extra cost that a firm typically has for searching for workers overseas.

[12] An alternative representation of the foreigner labor supply is the sum of past 6 years recruitment. These two representations are analogous in steady state and do not differ in terms of the implications for the model. For simplicity, we model foreign labor supply with a constant rate of separation.

[13] This is a common assumption in the dynamic labor demand literature and including capital in the production function generally does not change quantitative results (Kline (2008)).

[14] As it will become clear later, a different way to state the assumption is that the monopsonistic firm that hires CS cannot wage discriminate workers on the basis of their age or nationality.

As we mentioned earlier, an important feature of the model is that we model the employer as a monopsonistic. The representative firm is a monopsonist with regards to the U.S. labor market for computer scientists and faces the same upward sloped supply as is faced by the sector.

### 3.3.1 Firm's Decision

The monopsonistic firm is forward looking and makes employment and wage decisions based on the information available at the begging of each period, which is a subset of the information available to individuals. Specifically, the set of information $\Psi_t$ available to the firm is:

1. The number of American CS at different ages employed at beginning of each period: $L^a_{t-1}$.
2. The number of foreign CS at beginning of each period: $F_{t-1}$.
3. The number of recent college graduates with a CS degree: $C_t$
4. The productivity level of the firm: $A_t$.[15].

We establish the firm's decision as a dynamic monopsonistic problem. The firm chooses wages, American employment and foreigner recruitment in order to maximize intertemporal profits, as represented by the Bellman equation:

$$\pi(\Psi_t) = max_{w_t,L_t,R_t} A_t Y(L_t + F_t) - w_t(L_t + F_t) - C_F(R_t) - C_L(L_t - L_{t-1}) + \beta_2 \mathbb{E}_t[\pi|\Psi_{t+1}]$$

subject to American and foreign labor supply:

$$L_t = \sum_{a=22}^{a=65} L^a_t(w_t)$$

$$F_t = (1 - s)F_{t-1} + R_t$$

where $A_t Y(.)$ is the production function, $C_R(.)$ is the recruitment costs of foreigners and $C_L(.)$ is the adjustment costs of Americans,.

[15]In the labor supply section we defined wages of the other occupation and the number of college graduates as exogenous and perfectly foreseen by agents, so we omit these two variables here.

Now we turn to the parameterization of both the production and recruitment costs functions. For simplicity, we choose to represent the production function as Cobb-Douglas, such that $Y(L_t+F_t) = (L_t+F_t)^\gamma$, for some $\gamma$ between zero and one. This parameterization guarantees a decreasing marginal return to labor and thus an interior solution for the employment decision of the firm.

Additionally, we assume that recruitment costs of foreigners include both linear and quadratic components $C_R(R_t) = c_{R1}R_t + c_{R2}R_t^2$ and the American adjustment costs include only a quadratic term $C_L(L_t - L_{t-1}) = c_L(L_t - L_{t-1})^2$. The linear term in the foreign recruitment cost represents expenditures that are required for hiring each foreign worker, such as application fees. The quadratic parameterization is convenient because an increasing marginal recruitment costs prevents firms of completely substituting Americans for foreigners workers[16].

In a typical monopsonistic problem (Manning (2003)), the solution to the firm's problem can be characterized by both the first order and envelope conditions with respect to the wage level. In addition, in our model the firm can also choose the number of foreigner recruited at each period and therefore we also consider the first order and envelope condition for the variable $R_t$.

Taking the first order condition of the firm's maximization problem with respect to wages and taking into account the labor supply function of American workers, lead us to the following equation.

$$\{A_t\gamma(L_t + F_t)^{\gamma-1} - w_t - 2C_L(L_t - L_{t-1})\}\frac{\partial L_t}{\partial w_t} + \beta\mathbb{E}_t[\frac{\partial \pi(\Omega_{t+1})}{\partial w_t}] - L_t - F_t = 0 \quad (4)$$

and using total differentiation, we take the derivative of future profits with respect to current wages:

$$\frac{\partial \pi(\Omega_{t+1})}{\partial w_t} = \sum_{a=22}^{a=64} \frac{\partial \pi(\Omega_{t+1})}{\partial L_t^a}\frac{\partial L_t^a}{\partial w_t}$$

where $\frac{\partial L_t^a}{\partial w_t}$ is the derivative of the labor supply function of Americans at age $a$ with respect to wages that is presented in the appendix of the paper.

The next step is to define $\lambda_t^{a-1} = \frac{\partial \pi(\Omega_t)}{\partial L_{t-1}^{a-1}}$ as the shadow price of past employment of workers age $a-1$ on current profits. Using the envelope condition, we can differentiate the profit function with respect to past employment, such that for any age $a$ between 23 and 65:

[16]Quadratic labor adjustment costs has also been widely used in dynamic labor demand literature: Sargent (1978) and Shapiro (1986).

$$\lambda_t^{a-1} = \{A_t\gamma(L_t + F_t)^{\gamma-1} - w_t - 2C_L(L_t - L_{t-1}) + \beta\mathbb{E}[\lambda_{t+1}^a]\}\frac{\partial L_t^a}{\partial L_{t-1}^{a-1}} + 2C_L(L_t - L_{t-1})$$

where $\frac{\partial L_t^a}{\partial L_{t-1}^{a-1}}$ is the derivative of the labor supply of workers age $a$ with respect to workers age $a-1$ that is also presented in the appendix of the paper. Note also that the employment of workers at age 65 does not affect future earnings, such that $\lambda_t^{65} = 0$.

On top of choosing wages, the firm also decides the number of foreign recruited at each period. The first order condition of the firm's problem with respect to $R_t$ is given by:

$$A_t\gamma(L_t + F_t)^{\gamma-1} - w_t - c_{R1} - 2c_{R2}R_t + \beta\mathbb{E}[\frac{\partial\pi(\Omega_{t+1})}{\partial R_t}] = 0 \ (5)$$

Finally, the shadow price of past foreign recruitment on current profits can be derived using the envelope condition with respect to past recruitment, such that:

$$\frac{\partial\pi(\Omega_t)}{\partial R_{t-1}} = (1-s) * \{A_t\gamma(L_t + F_t)^{\gamma-1} - w_t\}$$

### 3.4 Equilibrium

In the past section we derived the optimal choice of individuals and firms. A dynamic general equilibrium can be characterized by the system of equation that represent those choices and the stochastic process of technological progress $A_t$. In particular, equation (1) characterizes the expectations of workers with respect to future career prospects, equations (2) and (3) are the dynamic labor supply of American and foreigner computer scientists respectively, and equations (4) and (5) describe the dynamic labor demand for American and foreign CS.

The last piece to characterize the equilibrium of the model is to define a stochastic process of technological progress. Note that $A_t$ is the only source of exogenous variation to the system. We decide to specify $A_t$ as a first order auto-regressive process, such that:

$$A_t = \rho A_{t-1} + (1-\rho)\bar{A} + \xi_t \ (6)$$

where $\bar{A}$is the steady state level of progress, $\rho$ is the autocorrelation parameter that lies between zero and one and $\xi_t$ is the random idiosyncratic productivity shock that is assumed to be independent of other variables of the model.

# 4 Calibration and Simulations[17]

In this section, we first calibrate the model to the US internet boom from 1994-2000. Our goal is to produce reasonable calibrated parameters, which we then use to simulate a counter-factual for this period where we fix foreign labor supply to its 1994 level.

## 4.1 Calibration

We model the internet boom as a steady increase in technological process, $A_t$, and we jointly calibrate this increase and how the rest of the parameters of the model respond to it. We first assume that the market is in a steady state in 1994 where $A_t = \bar{A}$, then $A_t$ grows by $\Delta_A$each year in a transition through the year 2000.[18] We assume workers and firms begin in steady state in 1994, expect $A_t$ to follow equation (6), but each year are surprised by the technology increase, through 2000. We set $\rho = 0.99$ and $\sigma_\xi = 0.001$, so these shocks are highly persistent.

We divide our remaining parameters into two groups for calibration. For the first group of parameters, $\{\beta, \gamma, s\}$, we choose what we consider reasonable values and set $\beta = .9$, $\gamma = .8$, and $s = \frac{1}{6}$.[19] For the second group of parameters, $\{c_{R1}, c_{R2}, c_L, \alpha_0, \alpha_1, \sigma_0, \sigma_1, c, \bar{A}, \Delta_A\}$ we calibrate the model using Dynare 4.3, a software library for solving and simulating Dynamic Stochastic General Equilibrium models.[20] We search this parameter space using the Nelder-Mead simplex method to find parameter values which yield solutions to the model that match four features of the data in each of two years, 1994 and 2000 (8 values total), in the US, following the above assumptions:

1. $L_t = \frac{\text{American computer science workers}}{\text{Americans with STEM degrees}}$

2. $F_t = \frac{\text{Foreigner computer scientists}}{\text{Americans with STEM degrees}}$

[17]This section is very preliminary. We are considering some alternative assumptions and methods in how we calibrate the model's parameters, particularly our assumptions about the demand shock process. Additionally, we plan to do sensitivity tests to understand how sensitive our simulations are to the underlying parameter assumptions.

[18]We recognize that these are strong, highly simplifying assumptions about the technological process behind the internet boom, particularly the constant growth rate assumption. We are working on modeling reasonable alternatives.

[19]In particular, we choose $s = \frac{1}{6}$ to correspond with the institutional features of the H-1B visa program. A worker's initial H-1B visa is valid for three years, but they may get an extension for an additional three years. The initial visas apply toward the annual cap, but extensions do not and are generally granted.

[20]Juillard (1996); Collard and Juillard (2001a,b) explain the solution methods Dynare uses.

3. $w_t = \frac{\text{Log(Weekly wages for computer science jobs)}}{\text{Log(Weekly wages for other STEM jobs)}}$

4. $p^c_{t+4} = \frac{\text{US computer science degrees awarded (lagged 4 years)}}{\text{US STEM degrees awarded (lagged 4 years)}}$[21]

This process produces the calibrated parameters found in Table 3.[22] In the simulation in the next section (4.2), we provide context to these parameters.

We calibrate the model, rather than estimating it because of fundamental data limitations. Due to the annual cycle of both the H-1B immigration and college graduation processes, we use annual, not finer-grained data. The short time-period we primarily study (1994-2000) thus does not provide us with enough data points to estimate the model.

## 4.2 Simulation of Fixed Foreign Worker Population Counter-Factual

We use our calibrated model to simulate a counter-factual internet boom from 1994-2000, where we hold $F_t$ constant at its 1994 value, assuming the same technological process as in Section 4.1. We show our results in Figure 13, where we compare the data to the full model and the counter-factual simulation.We first note that because of the simplistic technological process assumption, our full model generally only matches the broad trends in the data and not the annual variation.

Overall, in the counter-factual, firms increase wages to hire more American workers when they can no longer increase foreign employment. The top-left panel shows how we hold $F_t$ fixed in our counter-factual at 2.4%, while it actually increased from 2.4% to 8.2% in the data (and in our full-model by construction), an increase of 346.9%. In the data and our full model, American CS workers increase from 31% to 40% of all STEM workers. In the counter-factual, they instead increase to 43% of all workers. Thus, we simulate that if firms were unable to recruit additional foreign CS workers, by 2000, they would have instead increased their employment of American CS workers by only 54% of the foreign worker shortfall. Total employment in the CS sector in the

[21] Uses data from 1998 and 2004, representing enrollment decisions in 1994 and 2000.

[22] Since our system is formally underdetermined, it may be the case that these parameters are not a unique solution to our system, and even if they are, it would be a difficult point to prove. We find the simulated paths of our four key variables to be reasonable, and thus use our judgment to accept our parameter estimates as thus being reasonable, following other authors who use this style of evaluation when calibrating economic models, dating back to Kydland and Prescott (1982).

US increased from 33.7% to 47.8% of all American STEM workers, but without additional foreign recruitment, we simulate an increase to only 45.5%,

Over 1994-2000, wages for relative wages American CS workers increased by 15%, relative to other STEM workers. In our counter-factual, firms instead increase wages by 23% to attract more American workers to the sector in the absence of additional foreigners. Enrollment in CS responds to increasing wages. In the data, CS enrollment more than double, increasing from 9% in 1994 to 19% in 2000. In the counter-factual, it grows faster and increases to 28%.

To sum up, our model predicts that restrictions on the recruitment of foreign CS would have a significant impact on the market for American computer scientists. In particular, wages in the year 2000 would be 6 percentage points higher relative to other STEM occupations, an increase that is just a little less than half of the total earning gains that happened during the Internet boom. Furthermore, in an economy with foreign restrictions, enrollment in computer science would be 9.36 percentage points higher, meaning that a significant share of the foreigner workers could be replaced in the long run by domesticity trained workers.

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# Appendix

Below we present some important derivatives used in the paper. For the derivations we used properties of the logistic function and total differentiation rules.

a) Derivative of transition probabilities with respect to wage:

$$\frac{\partial p^{co}_{t,a}}{\partial w_t} = -(1 - p^{co}_{t,a}) * p^{co}_{t,a}/\sigma_1 \text{ and } \frac{\partial p^{oc}_{t,a}}{\partial w_t} = (1 - p^{oc}_{t,a}) * p^{oc}_{t,a}/\sigma_1$$

b) Derivative of domestic labor supply of workers at age $a$ between 23 and 65 with respect to wage:

$$\frac{\partial L_t^a}{\partial w_t} = [(1 - p_{t,a}^{oc}) * p_{t,a}^{oc}/\sigma_1][M_{t-1}^{a-1} - L_{t-1}^{a-1}] + [(1 - p_{t,a}^{co}) * p_{t,a}^{co}/\sigma_1]L_{t-1}^{a-1}$$

Derivative domestic labor supply of workers at age 22 with respect to wage:

$$\frac{\partial L_t^{22}}{\partial w_t} = [(1 - p_{t,a}^{oc}) * p_{t,a}^{oc}/\sigma_1][M_{t-1}^{a-1} - C_t] + [(1 - p_{t,a}^{co}) * p_{t,a}^{co}/\sigma_1]C_t$$

c) Derivative of total domestic labor supply with respect to wages

$$\frac{\partial L_t}{\partial w_t} = \sum_{a=22}^{a=65} \frac{\partial L_t^a}{\partial w_t}$$

d) Derivative of current domestic labor supply of workers at age $a$ between 23 and 65 with respect to past domestic labor supply of workers at age $a-1$:

$$\frac{\partial L_t^a}{\partial L_{t-1}^{a-1}} = (1 - p_{t,a}^{co} - p_{t,a}^{oc})$$

**Table 1 - Estimates of Occupational Categoriees of H-l Non lmmlgrants Who Worked In the Unlted State, Northern and Eastern INS Regions - 1989**

| Occupation | Number | Percent |
|---|---|---|
| Nursing, health care, medical, and related | 16,689 | 27.7 |
| Education or research | 10,127 | 16.9 |
| Entertainment, movies and television, modeling, and allied | 9,764 | 16.2 |
| Engineering, science, and related | 8,813 | 14.6 |
| Computers, programming, and related | 6,894 | 11.4 |
| Other occupations | 7,333 | 12.1 |
| Did not respond | 636 | 1.1 |
| Total | 60,256 | 100 |

Source: GAO 1992, p. 33

**Table 2 - H-1B Petitions Approved by Detailed Occupation of Beneficiary, 1999**

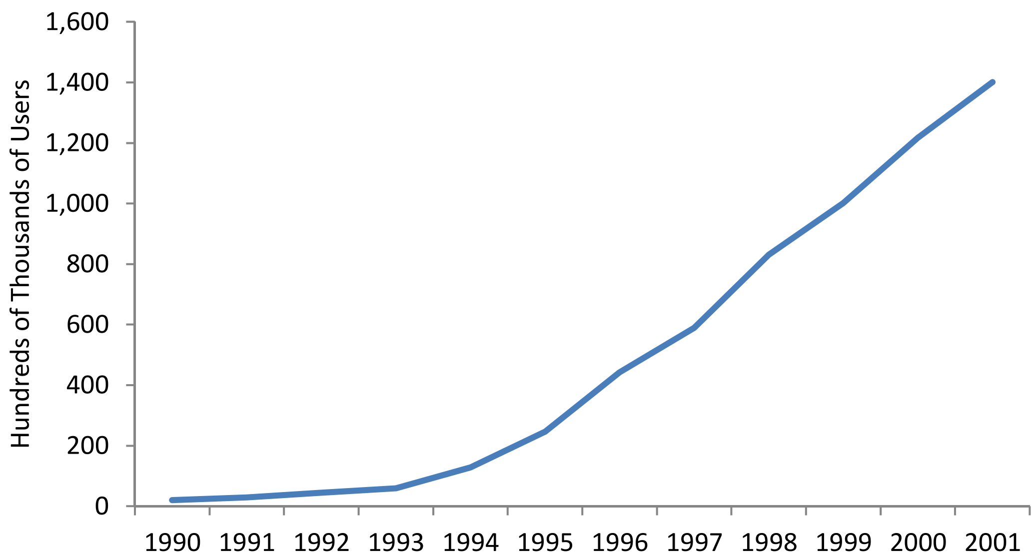
| Occupation | Number | Percent |
|---|---|---|
| Occupations in systems analysis and programming | 132,745 | 52.0 |
| Electrical/Electronics engineering occupations | 12,094 | 4.7 |
| Computer-related occupations, n.e.c. | 10,487 | 4.1 |
| Occupations in colleges and university education | 9,165 | 3.6 |
| Accountants, auditors, and related occupations | 8,586 | 3.3 |
| Occupations in architecture, engineering, and surveying, n.e.c. | 6,965 | 2.7 |
| Occupations in economics | 4,883 | 1.9 |
| Other occupations | 70,110 | 27.7 |
| Total | 255,035 | 100 |

Source: INS 2000, p. 9

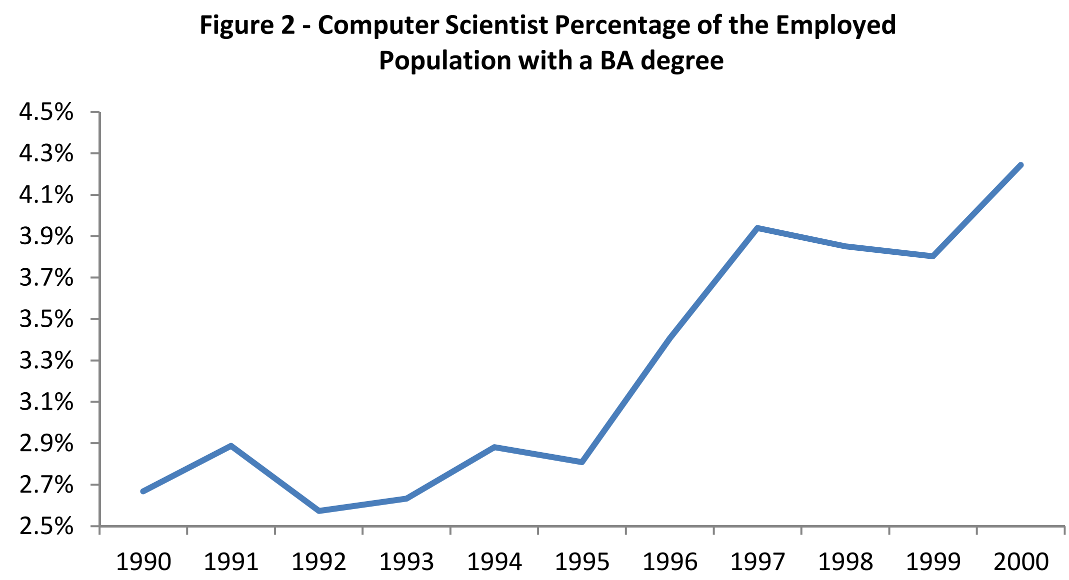
Table 3 - Calibrated Parameters

| Parameter | Description | Calibrated value |
|---|---|---|
| $c_{R1}$ | Foreign linear adjustment cost | 3.63 |
| $c_{R2}$ | Foreign quadratic adjustment cost | 0.51 |
| $c_{L1}$ | Domestic quadratic adjustment cost | 0.58 |
| $\alpha_0$ | Mean taste for not studying CS | 0.38 |
| $\alpha_1$ | Mean taste for not working in CS | -1.07 |
| $\sigma_0$ | Std. dev. of taste for not studying CS | 0.44 |
| $\sigma_1$ | Std. dev. of for not working in CS | 1.96 |
| $c$ | Sector switching cost | 3.50 |
| $\bar{A}$ | Steady state technology level | 5.53 |
| $\Delta_A$ | Annual technology growth | 0.73 |

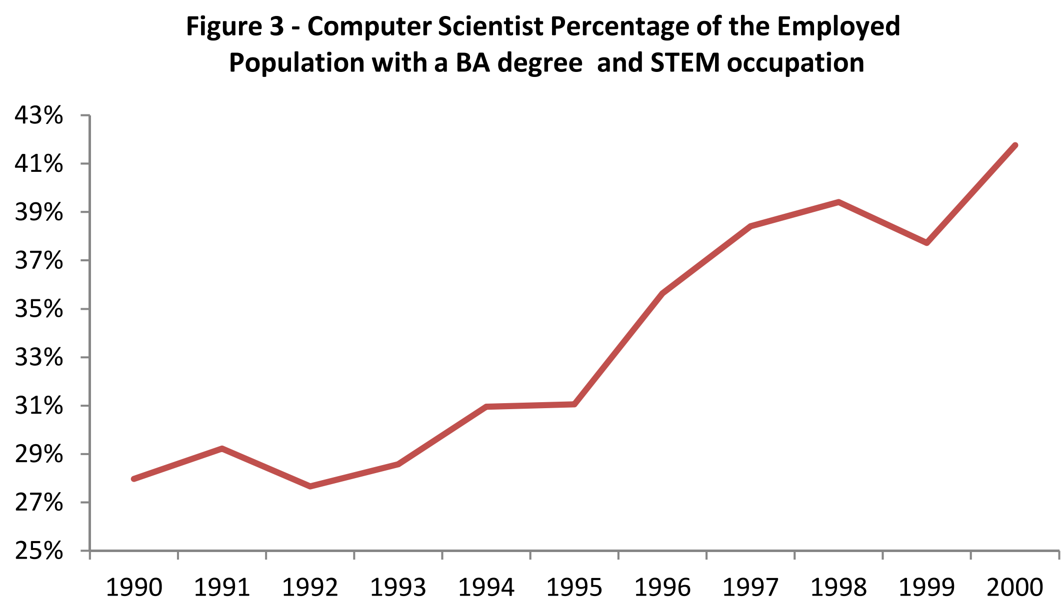
**Figure 1 - Number of Internet Users in the US**




Source: World Development Indicators - World Bank

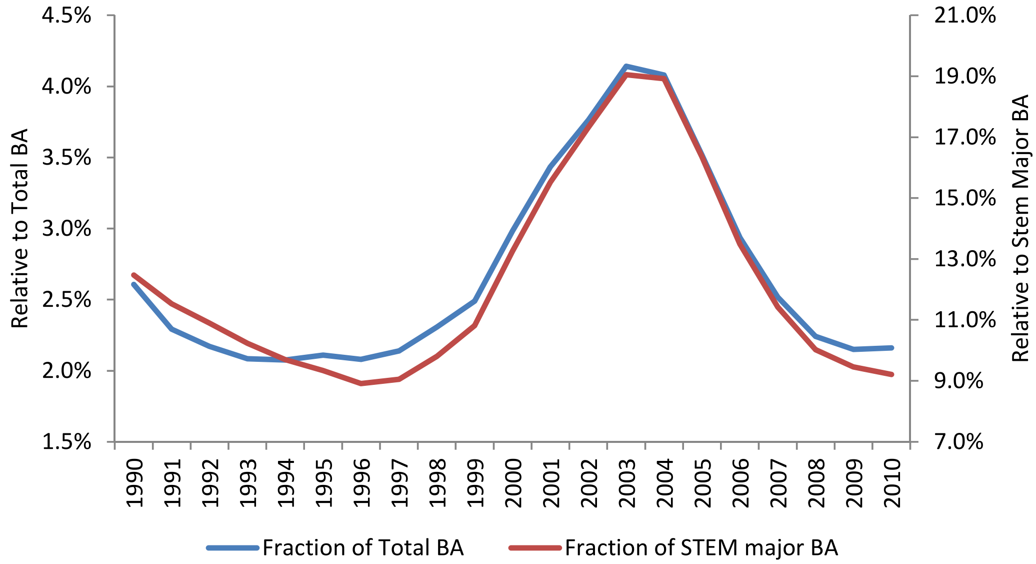



Note: Computer scientists are defined as computer systems analysts, computer scientists and computer software developers. Source: IPMUS March CPS



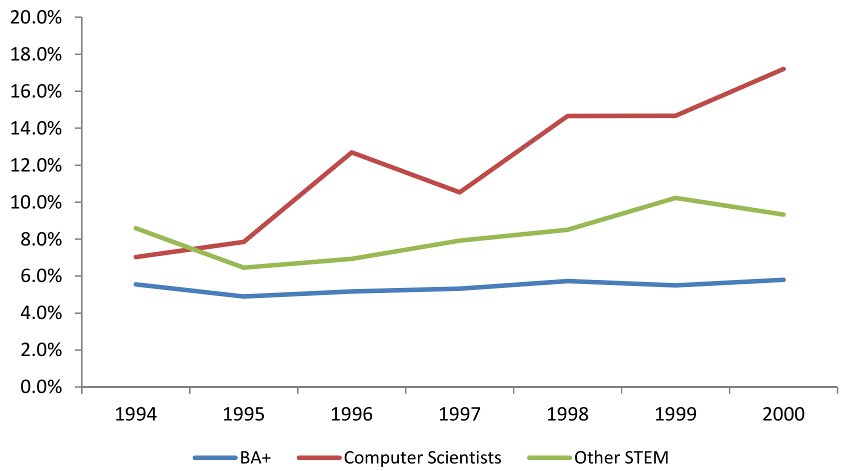

Note: Computer scientists are defined as computer systems analysts, computer scientists and computer software developers. STEM occupations are defined as engineers, mathematical and computer scientists, and natural scientists. Source: IPMUS March CPS.

**Figure 4 - Computer Science Fraction of BA Degrees Awarded**



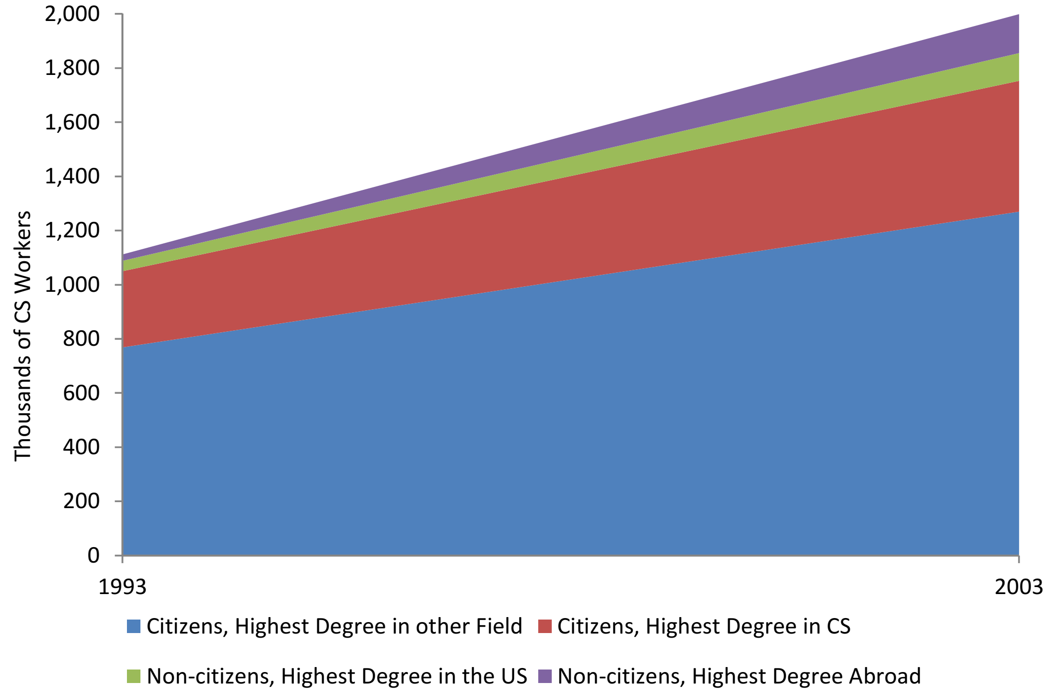

Note: STEM majors are defined as engineering, computer and math sciences and natural science. Source: IPEDS Completions Survey.

**Figure 5 - Non-Citizen Fraction of Total Employment by Occupation**



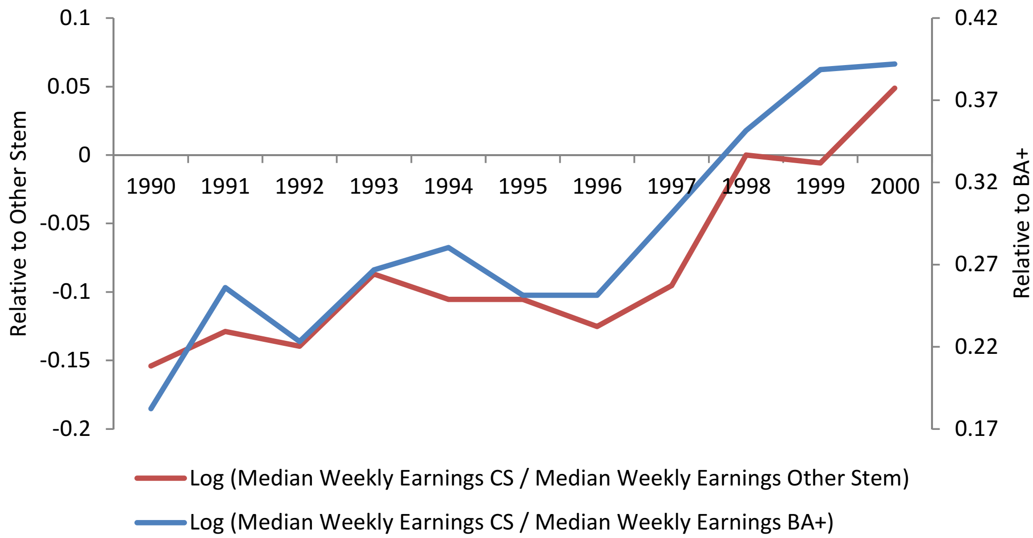

Note: Computer scientists are defined as computer systems analysts, computer scientists and computer software developers. STEM occupations are defined as engineers, mathematical and computer scientists, and natural scientists. Source: IPMUS March CPS.

Figure 6 - Origin of Computer Sientists Workers

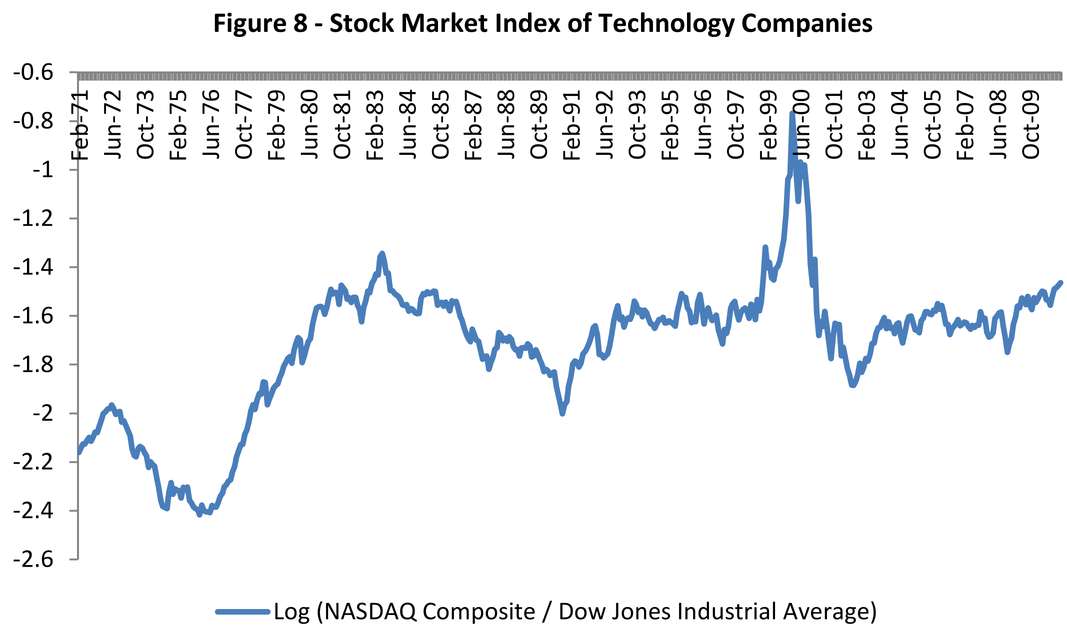



Note: Computer scientists are defined as computer and information scientists and computer programmers. CS field of study is defined as computer and information sciences. Source: NSCG 1993 and 2003.

**Figure 7 - Relative Earnings of Computer Scientists**

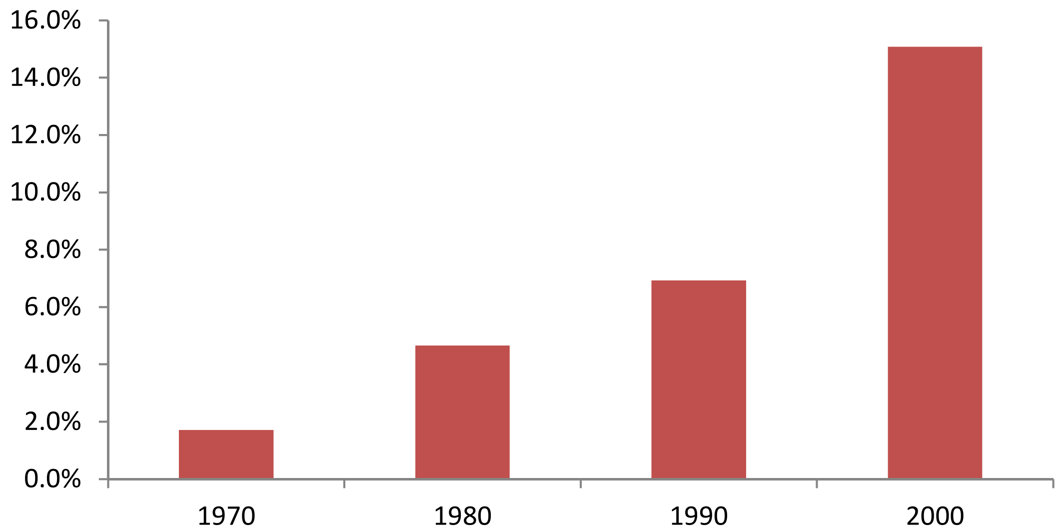



Note: Computer scientists are defined as computer systems analysts, computer scientists and computer software developers. STEM occupations are defined as engineers, mathematical and computer scientists, and natural scientists. Source: IPMUS March CPS lagged by one year.

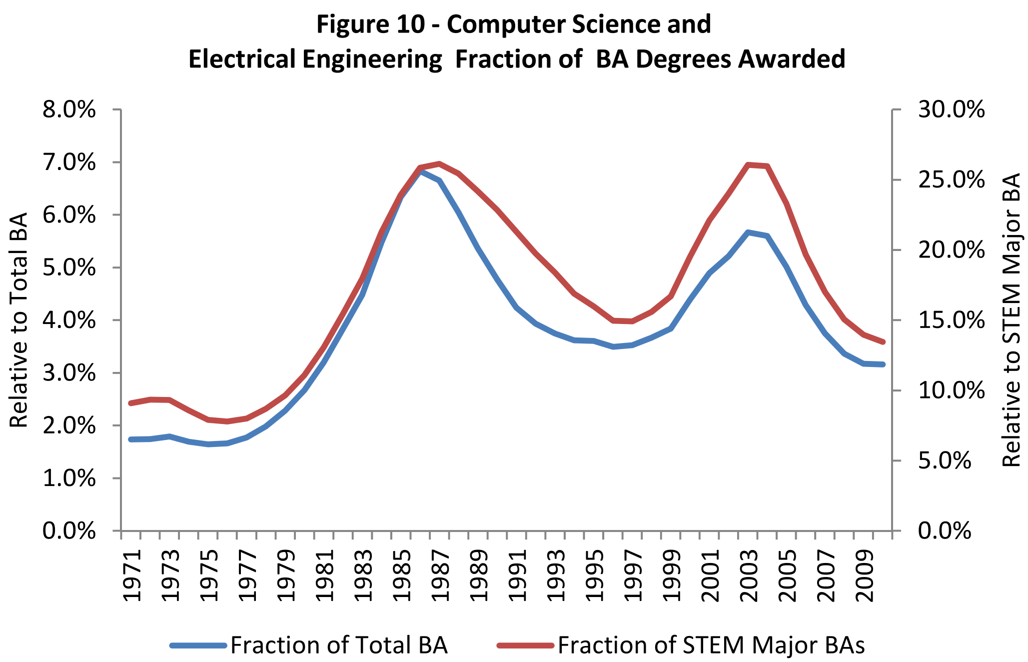



Source: Yahoo Finance website.

**Figure 9 -Non-Citizen Fraction of Total Computer Scientists**

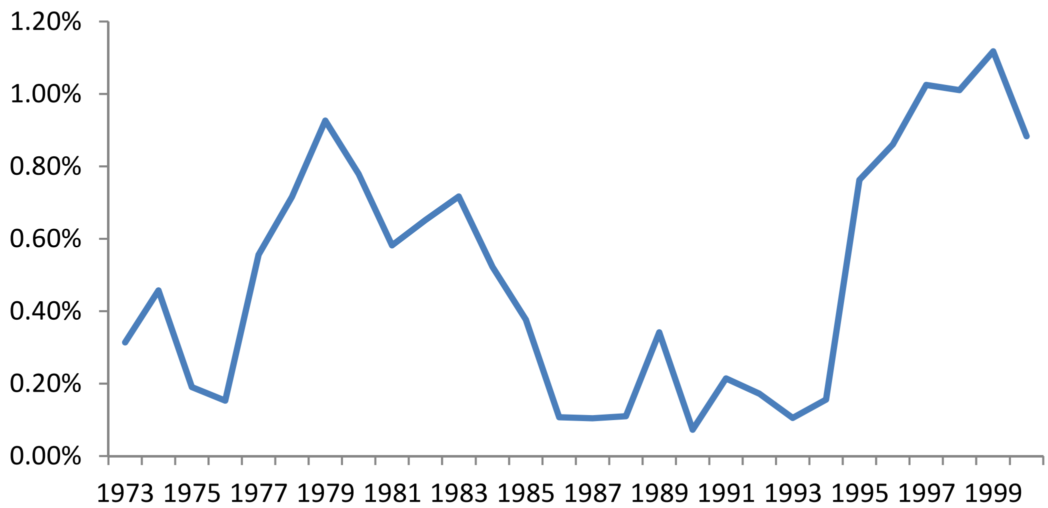



Note: computer scientists are defined as computer systems analysts, computer scientists and computer software developers. We restrict to workers with at least a bachelor degree and use IPMUS suggested occupational crosswalk. Source: IPMUS Census



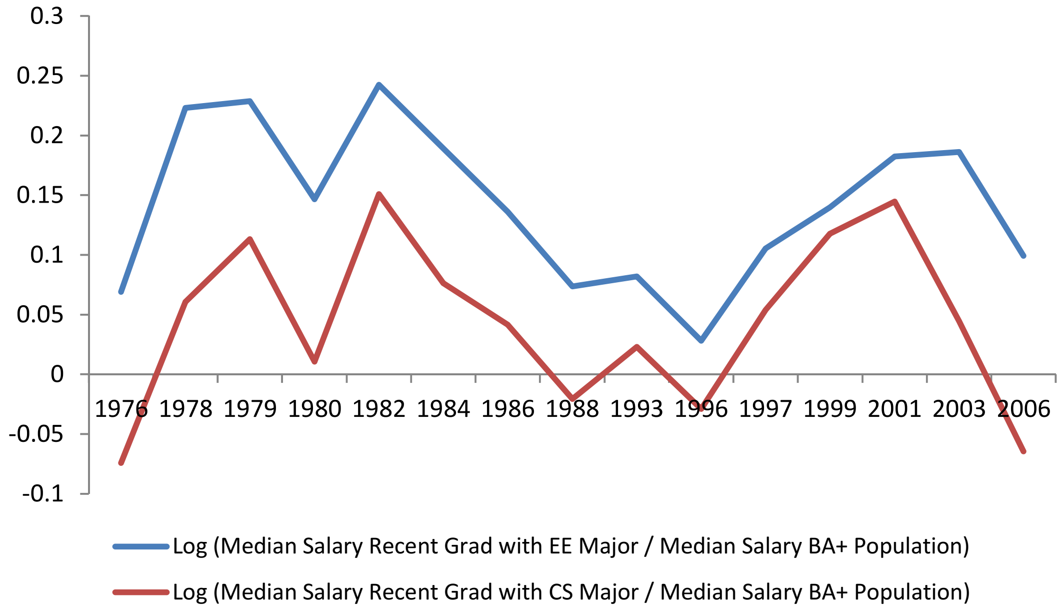

Note: STEM majors are defined as engineering, computer and math sciences and natural science. Source: IPEDS Completions Survey.

**Figure 11- % Change in Employment**
**Computer Scientists & Electrical Engineers**



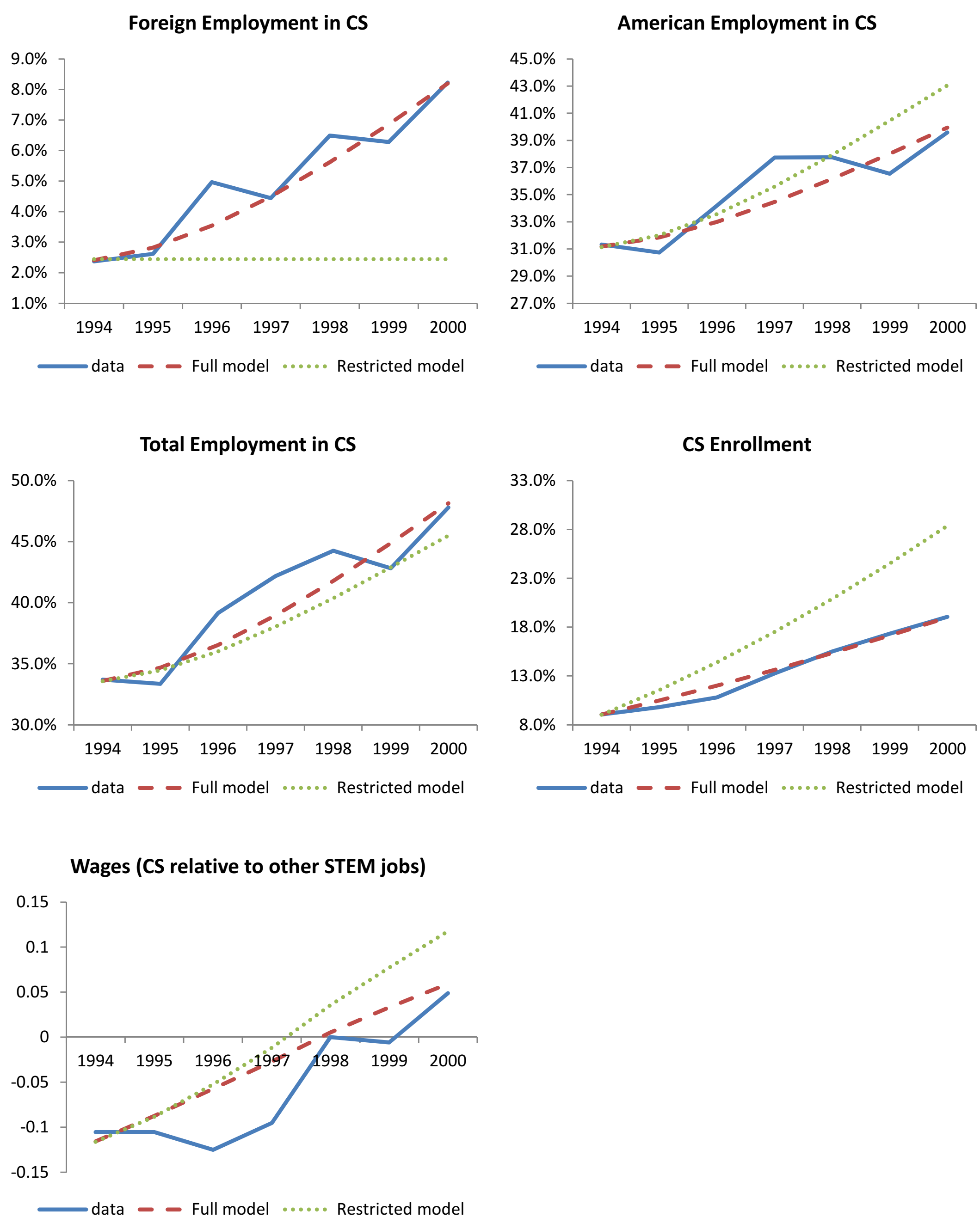

Note: The percentage change in employment is calculated by the authors using fixed coefficients manpower requirements model (Freeman (1980)). Source: we use CES for industry employment information and the IPMUS Census between 1970 and 2000 for occupational employment shares.

**Figure 12 - Relative Earnings of CS and EE**




Note: CS major is defined as computer and information sciences bachelor degree and EE major is defined as electrical, electronic, and communication engineering bachelor degree. Source: Annual salary information for recent graduates is obtained from NES from 1976 to 1988 and from NSRCG from 1993 to 2006. We restrict the sample to individuals working full-time. Annual salary information from BA+ population is obtained from IPMUS March CPS (lagged by one year). We restrict the sample to men working full time with at least a bachelor degree.

# Figure 13: Comparison between data, model and counter-factual




Note: The restricted model counter-factual fixes foreign employment to its 1994 ratio to American STEM workers.