8-2011

Worker Shortage, Outsourcing, and Immigration as Features of Computer Technology Competition between the United States and India

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I am submitting herewith a thesis written by Melvin L. Tobias entitled "Worker Shortage, Outsourcing, and Immigration as Features of Computer Technology Competition between the United States and India." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Economics.

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WORKER SHORTAGE, OUTSOURCING, AND IMMIGRATION AS FEATURES OF

COMPUTER TECHNOLOGY COMPETITION BETWEEN THE UNITED STATES AND

INDIA

A Thesis
Presented for the
Master of Arts
Degree
The University of Tennessee, Knoxville

Melvin L. Tobias
August 2011

ABSTRACT

In this study, we examine questions relating to the state of competition between the United States and India in the field of computer technology. We consider whether there is continual increase in the outsourcing by American firms of computer service work abroad, claims of computer worker shortage, and claims of the need for increased immigration of foreign computer workers to deal with a supposed deterioration in American technology. We conclude, first, that both U.S. and Indian computer service companies and their potential clients prefer close collaboration rather than "arms length" relationships. As a result, service companies in both nations have made large efforts to set up business in each other's country. Second, we find that the actual level of effort to hire workers in computer technology does not correspond to the intensity of need claimed by computer industry leaders. Finally, we conclude that the United States occupies a position of vigorous leadership in science and technology, evidenced by the largest number of graduates in those fields of any country, a number enhanced by a strong inflow of highly qualified students from other countries seeking advanced training and future careers here.

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I. Introduction

This study began as an investigation of the idea that computer programming – a shorthand term we use here to denote the many aspects of information technology or "IT" -- in the United States was in the process of being "outsourced" to overseas entrepreneurs in India and China. American businesses would be motivated to contract such work abroad because it would be far more cheaply done in these relatively low wage countries by personnel who, it was thought, were far more competent than US workers. Examination of data and information on the subject revealed that the situation was far more elaborate than that pictured in this oversimplified scenario.

Computer programming, while it, and the fields of computer science and computer engineering on which it is based, involve only a small population in any country, is, in fact, a matter of vital importance. It is axiomatic that in the present world, the presence of a well-functioning cadre of experts, knowledgeable on the highest, most advanced levels in the fields of computing technology and computer software are as essential to the efficient functioning of a society as, say, widespread competence in its general population in reading and writing or in everyday arithmetic reckoning. Electronic computers are basic to every function of modern industrial nations, whether one thinks of commerce, engineering, physical science, military defense, or even in politics (Political Participation 2011). In fact, services of thoroughly trained and actively engaged computer professionals are, in my opinion, at least as essential to a nation as an army, and, as with an army, this competence cannot be abandoned to the equivalent

of foreign mercenaries. Thus, we may have an economic situation where other countries may have a comparative advantage in this field, but where protectionism may be called for out of necessities that are not driven by economic forces. If one follows Ricardo's classic wine and cheese example, if nation A has a comparative advantage over nation B in producing product X, then nation B should not waste its resources making X but rather buy it from nation B and find something else to produce to provide a satisfactory trade balance. In Ricardo's model, the effect of trade in the right circumstances can make more goods available to all at equal or less cost.   However, because of the special existential role of computer technology, nations cannot take the course of abandoning their competency in it to others. When existential needs are not attended to, serious consequences may result. For example, our failure to put a rational energy policy in place has left the United States vulnerable to the instabilities of the OPEC cartel and other oil suppliers.   A less well known instance, but nevertheless quite significant, is our recent realization that we have neglected to assure our supply of rare earth elements, which have widespread and essential modern industrial uses. We now find that China has attained a virtual monopoly in their production and has given evidence that it is prepared to use the power of that position to extract concessions from other nations. (Krugman, 2010) Our purpose here is to determine, to what extent we can, whether the position of United States in the field of computer science and technology is deteriorating similarly.

The commonly held views of the US relationships with other countries in the field of computer programming are so contradictory that they must involve considerable distortions of the facts. Totally opposing views are stated, often with considerable heat.

The arguments, and indeed the whole question of the position of the United States in computer science, centers on the allegation that there is a shortage of qualified American workers, a shortage that, it is said, can be remedied by a combination of outsourcing computer work to foreign countries, by importing foreign computer technicians, and by encouraging more American students to major in computer technology.   Prominent representatives of IT industry (Hart 2008) have warned that the nation is in danger because there is a shortage of competently trained programmers. This condition is claimed to result from the combined effects of a supposedly inferior American education system that fails to teach mathematics and science as well as other countries do, and of a waning interest in our youth in careers in technological fields. (Aspray, W., Mayadas,F., & Vardi,M., Editors, 2006) The industry regularly urges need for drastic increases in importing foreign workers in order to stay competitive. Vigorously opposing such views are workers' groups such as the Programmers Guild (Programmers Guild, 2009) and other advocates of various political stripes.   Amid all the noisy disputation, even the meaning of the word "shortage" itself becomes suspect. Does "shortage" mean a lack of job candidates competent to do programming work, in the sense of a demand for a supply of domestic workers for which there are no adequate incentives, as industry groups maintain, or does it mean, as the statements of unemployed programmers assert, merely a claim to mask the desire of the industry to have, one way or another, a cheaper work force, as they refuse to hire the workers that are there?

These views, though obviously contradictory, do not necessarily mean that one is entirely true and the other entirely false. In fact, we shall show here that neither position

is properly relevant to the situation. The actual behavior of IT companies and personnel internationally does not conform to the outsourcing scenario we initially supposed existed.

We have chosen to give primary attention to one foreign country, India, in order to concentrate attention on the most important aspects of the international commerce of information technology. Although other nations are certainly important – China, of course, is a major and rising actor in this field, as is Taiwan – the "Indian connection" is most obvious and understandable. The first and most prominent reason for the relationship is that English is commonly used by educated Indians, which makes communication between their technologists and ours relatively easy.   Second, India's society and government have strong similarities to those of the United States with respect to political institutions and private enterprise. Third, India's IT economy is an activity of their large corporations, and as a competitor in the field, India may be thought of, if not equal, as "our size," certainly more so than nations like Ireland (population, 4.6 million) or Israel (population, 7.4 million). While such countries are active and advanced in the practice of computer technology (Central Intelligence Agency. 2011), they havenowhere near the capacity of India, with its more than a billion population, to provide an information technology work force comparable to that of the United States.

The structure of our discussion is based on dealing with the worker shortage question. We begin by describing important background aspects:

1.   An outline describing the work of computer professionals.

2. The education and training of computer professionals in the United States.

3. A description of the capabilities of India's technologists.

We next present the opposing views concerning the existence of a shortage and how advocates of one side or the other claim it may be dealt with:

4. The views of information technology workers groups and others that there is no actual shortage, that industry resists hiring US workers in the hope of replacing them with cheap foreign labor. Important representations of this viewpoint are the testimony by Prof. Norman Matloff before the House Judiciary Committee in 1998, and the RAND Corporation report (Galama and Hosek, 2008) on the adequacy of technological capability generally in the U.S. Included in this section is a description of various aspects of the importation of foreign computer technologists.

5. The view of industry that an adequate supply of competent US workers does not exist. This is asserted to be dealt with by both outsourcing computer work abroad, a practice for which valuable benefits are claimed, combined with allowing increased immigration of foreign technologists.

We continue with a description of the actual practice of computer work in the United States and the supply and status of computer workers:

6. The realities of outsourcing computer work in providing "arms length" computer services; the concept of a non-tradable good and the "flat world" activity of both Indian and US information technology companies.

Next we consider aspects of the situation using available data that enable conclusions to be drawn:

7. First, it is implied by industry that the world position of the United States as a source of graduates in computer technology (and other technologies as well) has deteriorated to the point where the US is falling behind other nations. It is therefore claimed that we

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must import increased numbers of foreign workers to maintain competitiveness. It is also argued that while many foreign students come to the United States to obtain advanced education, our immigration policies drive them away. We find that data concerning the production of technologists in the United States and the post-graduation behavior of foreign students indicate rather that such assertions grossly distort the actual circumstances.

8. It is argued by many that if there were an actual shortage of computer workers that wages would rise strongly as industry strives to attract the needed employees. We have examined and compared the wage status of US computer workers, employment/unemployment data, and the time variation of real (inflation corrected) wages over the past decade. We find that the wage and employment picture shows that while IT workers are better off than the average US worker, increases in wages over time largely correspond to rises in the Consumer Price Index and thus are no different in growth (or the lack thereof in real terms) from the wages received by the average US worker. Only "elite" worker categories, such as computer scientists, show any steady increases in real (inflation-corrected) wages, and these are modest.

We end by listing out conclusions. In brief, we do not believe a shortage of computer workers exists or that immigrants of signal ability are being driven off. There are no indicators of desperate need, but there remain serious questions concerning the fate of unemployed and older computer workers.

II. What Computer Professionals Do

In this section, we outline the nature of the work of computer professionals and what they have to deal with. This descriptive material is based on a variety of sources, such as the author's own professional experience, the job definitions for Standard Occupational Codes published by the US government's Bureau of Labor Statistics as well as their Occupational Outlook Handbooks, anecdotal conversations over many years with computer professionals, and the like. The use of computers started out with simple "number crunching" of data for the use of such businesses as insurance companies, or governments wanting to make sense of census information. As computing machines became more sophisticated, they were applied to scientific and engineering problems with ever increasing success. A widening succession of applications has occurred and continues.   Information on the career activities of some programmers after graduation from the University of Tennessee is presented to indicate the variety of involvements that exist in this profession.

A computer is a machine that can carry out arithmetic and logical operations on numerical data using a set of instructions called a program. The people employed to create these instructions are called programmers. Their level of training may range from that acquired in a vocational school lasting a few hundred hours to that offered in Ph. D. graduate courses in computer science of high theoretical sophistication at major universities. Additionally, there are a surprising number of excellent programmers who are self-taught.

Complementary to the mental, pencil-and-paper (or equivalent) activity of programming and overlapping it is the field of computer engineering, which deals with

the design, and manufacture of computers of various kinds to carry out the programmed instructions as efficiently as possible. Computers are made in a very large range of physical types and sizes, depending on the functions they are intended to serve. The invention of devices based on solid-state physics and chemistry, starting with the transistor and advancing over the years into integrated circuits and microprocessors, has enabled enormous increases in the amount of information that can be stored and equally enormous reductions in physical size and energy requirements. Early computers of the 1950s, such as the ORACLE at Oak Ridge National Laboratory (Information Acceleration 1994), used circuitry based on vacuum tubes and cathode ray tubes for data storage. These generated large amounts of heat, a cause of frequent component failures, which had to be dissipated by air conditioning the large room needed to house the computer. The memory was a few thousand binary digits ("bits", a bit being either a zero or a 1).   Primitive as such machines as the ORACLE were, it was instantly obvious to their users that they represented a truly revolutionary advance. Enormous improvements have been made since those days, and remarkably, the technology of computers continues to advance vigorously. Today, for instance, flash drives that are only 100 mm (4 inches) long and 16 mm across, easily carried in one's pocket, are sold with over 120 gigabytes (in computer jargon,1 byte = 8 bits; giga- : international standard numerical prefix for billion) of memory, millions of times the ORACLE's capacity.   Students and office workers have at their desks laptops and consoles that, in speed and data storage size, dwarf the building-floor size central computers of a couple of decades ago. Computers of the latter size are now called

"supercomputers" capable of dealing with problems of vast complexity, such as those arising in the modeling of weather on a continental scale.

Computer professionals are concerned with computer "hardware" and "software". "Hardware" refers to the physical equipment of computing – the computing processor itself and its auxiliary equipment – and software refers to the instructions that are given to the computer that enable it to carry out numerical and logical operations. These instructions are called "programs" or "computer code." There are different types of software. There is "system software" which manages the operation of the hardware in order to enable the computer to run in stable fashion, provide controls for auxiliary devices such as printers, displays, keyboards, speakers for sound, internet connections, etc. in such a way that they can be used as given features and need not be reinvented for every program. There is software that enables the writing of programs. Early computers such as the ORACLE required programmers to provide instructions for the most elementary operations, all in the notation of binary arithmetic, at the very "bit" level of the computer itself. Nowadays, programs for applications are written in so-called "higher level languages" that enable programmers to compose their ideas in a human-oriented intellectual format. The programmer usually creates his or her program or code in a higher-level language and reads these instructions into the computer. In the computer there is built-in software – the compiler -- that translates the higher-level language into "machine language" written in "words" made up of zeros and ones that will be instructions to the machine itself. (One is tempted to say that the computer "understands" machine language, but this is anthropomorphism. The computer is itself an unthinking machine that only obeys the instructions that the human programmer

gives it, whether these are right, wrong or meaningless.) A higher-level language

command may well generate many machine language commands after compilation.

Higher-level languages are portable – they can work on computing machines made by

different manufacturers. The compiler translates the commands into those appropriate

for its machine. Alternatively, the programmer may achieve a more efficient program

than a higher-level language can generate by use of <u>assembly language</u>. This is a

version of machine language that provides mnemonics that simplify the programmer's

use of routine machine language procedures. The use of assembly language has

become rare because modern compilers have achieved great efficiency that is usually

difficult to improve upon. An advanced technique, it is still occasionally resorted to for

specialized applications. Examples occur in the design of computer games, flight

navigation systems, high security systems, encryption, and for darker applications such

as virus generation, and hacking.

The higher-level languages such as COBOL, used for business applications,

FORTRAN, designed for engineering and scientific calculations, and BASIC, intended

as an easily learned introductory programming method, are historically important

examples, and still receive significant use. More modern languages are JAVA, C++,

and C#. There are a large number of languages beside these, designed to achieve

various kinds of efficiency improvement, whether in speed of operation of the resulting

code, or in simplifying the task of creating a program. One important simplifying

technique is <u>pseudocode</u>, in the use of which the programmer prepares the code using

a language something like one he is accustomed to -- it may include natural language

as well -- but leaving out complex details that are necessary for a real program but

unrelated with the logic of the program.   Once that has been laid out, it is relatively

easy to translate the pseudocode into any actual computer language.   Pseudocode is a

modern variant of the old practice of flowcharting but has the convenience of being

more easily understood in relation to the final version of the program. There are no

formal standards for writing pseudocode, nor is it intended, or even possible, to be read

directly into a computer. Pseudocoding is obviously useful for communicating ideas

between programmers working on the same project but distant from one another.

Conceivably, they might be using different formal languages.

      As has already been mentioned, a field closely related to computer programming

and overlapping it to a considerable degree is the discipline of <u>computer hardware

engineering</u>.   Computer hardware engineers design computing machines – "hardware"

-- and related logic-based equipment, whether it be a powerful central supercomputer, a

personal computer (PC), or some special control device for a novel situation. The

computer engineer's work may well involve programming as well as thorough

knowledge of electrical engineering principles.

      The designation "software engineer" has also come into use. There is some

uncertainty about this term and it is not clear to this writer how it differs from the term

"programmer".   The Bureau of Labor Statistics makes a definite distinction, however.   It

refers to some level of programming and does not refer to hardware design.

      The true professional programmer may be called upon to work on or create

programs for all of the aspects of computer operation that have so far been mentioned.

The journeyman programmer who has received only trade school training may know

one or two higher languages – often quite adeptly – but be at a loss when confronted by

some task such as creating or modifying a compiler for a specialized computer for, say, an automobile control system. Another particularly vital field in computer science, which calls for the best talents of a programmer, is that of computer security. This is the protection of the data in the computer and the computer itself from attacks by criminals, hackers and those who would commit mindless vandalism. Computer protection has the intrinsic problem of being in theory impossible of achievement if the machine can be publicly accessed. Those involved in computer protection can only engage in a never-ending battle of wits to make attacks impractical until such time as the attackers contrive a new method.

In addition to the intellectual demands of his or her work, the programmer is often under considerable pressure to produce results quickly, and as a professional, regularly called upon to work long hours to meet deadlines in a field where firms are facing severe competition. Employee morale and enthusiasm – or its lack -- is of crucial importance for the success of a project in such circumstances.

There is stratification in wages, employment, and status of computer workers highly dependent on which of the disciplines and activities we have described above they are engaged in. This will be further discussed below in conjunction with the discussion of wages and the shortage-question dispute.

III. Training of Computer Technologists in the United States

A. University Curricula in Computer Science and Engineering

A description of the undergraduate and graduate computer science and computer engineering curricula of the Electrical Engineering and Computer Science Department at the University of Tennessee (UT 2008-2009) is found in Appendix A. The merging of the two disciplines into one department is found at other institutions, such as the Massachusetts Institute of Technology's Electrical Engineering and Computer Science Department (Course VI 2008). The successful completion of the demanding courses required for a degree in the computer field at the University of Tennessee, like those at other large US schools should ensure that the student will be well prepared to enter the computer field on graduation. In particular there is considerable emphasis on theory, which provides the future professional with a basis essential for keeping up with the steady and rapid succession of innovations in the field.

Appendix B illustrates the variety of career activities in which computer science graduates may become involved. The appendix is a copy of a survey done some time after 2004 consisting of reports by University of Tennessee computer science alumni about their work. (This survey was published as an on-line news item and is not now available for viewing, but similar surveys done by other schools are easily found on the internet.)

B. Trade and Vocational School Training

Many trade and vocational schools offer training in computer programming. These courses last about a year, and those who undertake them, depending on the

school, can learn a great deal and attain a creditable level of competence. This is likely, however, to be in programming in a particular language, such as C++ and the graduate of such training cannot be expected to have the kind of breadth of intimate knowledge of computer operation and computer science that can be achieved in university courses.

C. Self-Education

In all scientific fields, there have been occasional experts and pioneers who had no technical education – or even no education beyond the grade-school level – yet pursued careers of distinction. Computer science has a similar, and even stronger such tradition. There are many present-day workers -- Bill Gates is a most prominent example -- who have been entirely self-taught. They acquired their knowledge when they became obsessed with such things as computer games at an early age and went on to learn, and then to innovate, with similar obsession.   Aside from such exceptional individuals, the most common way that self-taught individuals are employed would be in such jobs as "help desk" staff. At the University of Tennessee, for example, the Office of Information Technology maintains such a group to help students and faculty who phone in asking for assistance with computer problems. In this writer's experience, none of the personnel who have helped me, whether a student or a full-time worker is or was a computer science major. Nevertheless, all those I have encountered were quite competent. Rarely have these first-line employees had to seek assistance from higher-ranked employees – some of whom may themselves have possibly also been self-taught.

IV. Indian Education and Training in the Field of Information Technology

As has already been mentioned, in this work, attention is centered upon India and, when we began this study, the idea that American companies are progressively outsourcing programming work to India. We do not now believe that this is a significant factor in the interaction between the United States and India in the computer field but there are other important relationships. As we have remarked in earlier sections, Indian IT firms, in normal entrepreneurial fashion, have aggressively sought markets for their work in the United States and elsewhere in the world. Next, there are American firms, wishing to make use of Indian IT expertise, have set up shop in India itself and hired local programmers and information technology workers. Further, American firms and Indian firms also, have brought Indian programmers under the H-1B process. Many of these desire – and succeed -- in staying permanently. Another significant source of Indian technology workers are those who already have earned university educations in their country and come to the United States under student visas to obtain advanced degrees. A very large percentage of these remain in the United States, some to become successful entrepreneurs. (Varma. 2009), In an online essay in 2008, the web site "Maps of India™ ("Situations Responsible," 2008) gave, in rather extravagant style, reasons for job outsourcing to India. Globalization, the article stated, has increased inter-country competitiveness. The world is pictured as becoming increasingly cosmopolitan, with the idea of the national state becoming obsolete. Communication has made distance "immaterial" and the setting up of a relationship between overseas

programmers and the outsourcing company is represented as an easy matter, rapidly accomplished. India's Socialist era was described as a "constructive prelude" to present-day private enterprise activity. The huge population growth is seen as advantageous, offering, as the author puts it, a large labor force willing to work cheaply.

A particular advantage often found in Indian workers is that they are good at expressing themselves in English both orally and in writing. While only perhaps 3% of the Indian population is literate in English, it is felt to be a prestige language for higher education and used in elite schools.   Fluency in English is necessary for upward mobility in business, government, science and technology. That is understood not only by the upper classes but also increasingly by working-class parents as well, who, if they are able to, seek out English-language schools for their children. ("Languages of India," 1995.) Competence in English is a valued asset for those involved in international trade. When that competence is absent, as is often the case with countries other than India, serious difficulties may arise.   For example, interpreters are often hired to bridge the gap.   A recent article in the *Financial Times* (Clegg, 2010), cites some of the problems with that practice.   First of all, where technology or specialized businesses are involved, an interpreter may have a perfect understanding of the grammar and literary aspects of the language but be totally unfamiliar with the ideas and jargon used in the business under discussion. In such a case, the translations become worthless. Cultural barriers exist. In one case cited, a Japanese word was interpreted to mean "difficult", but to a Japanese it would have meant "impossible and we cannot do it."   Humor, for instance, must be avoided as it involves signaling too complex for proper transmission between languages. Psychological issues also can arise. Direct rapport must exist between the

agent who represents the business doing the outsourcing and those providing the

service desired, but attention may instead be diverted away from the agent, who should

be seen as giving the orders, to the interpreter instead. Not only may uncertainty result

over who said what, but in some cultures, loss of "face" may be suffered by the agent.

It is not necessary for present purposes to discuss the vast subject of Indian

society in any detail; we confine ourselves to those features of that nation relevant to

competition and interaction in the field of IT with the United States.

The population of India is estimated at over 1 billion (Central Intelligence Agency,

2011). It is obvious that, in so large a group, it should be possible to find and develop

many workers who would be both capable and motivated to work in technical fields such

as computer engineering and computer programming. Early in the post-colonial history

of India, its leaders believed that instituting a sophisticated system of advanced

technological education was necessary for achieving economic progress. They

established the <u>Indian Institutes of</u> <u>Technology</u> (Indian Institutes of Technology, 2010)

commonly called IITs, which are the flagship schools of Indian technical education.

The first IIT was started in 1951 on the site of a former British detention camp.

As of 2008, there are 13 IITs located in various parts of the country. On the basis of the

Joint Entrance Examination, the JEE, about 4000 candidates/year – published

estimates vary -- are accepted out of perhaps 600,000 applicants. The IITs, it is said,

have "the most demanding undergraduate entrance exam in the world." The total

enrollment is approximately 15000 undergraduates and 12000 graduate students.

Each IIT operates autonomously, the only overall supervision consisting of a general IIT

administrative council. While the schools have many courses in common, particularly at

the first year level, they have individual reputations for particular fields of study and specialized programs.

IITs receive generous monetary support from the government. There is a low student/faculty ratio. The QIP (Quality Improvement Program) was "set up to constantly update the expertise and capabilities of existing faculty."

Over the years, the IITs have come to be regarded as among the top universities in the world, and a large number of their graduates have achieved great success as entrepreneurs and managers internationally, and notably so in the United States. A 1998 Business Week article refers to "the IIT grad is the hottest export India has ever produced."   This striking assessment may give the impression of an invincible technological juggernaut – which is, incidentally, a term derived from the Sanskrit name for an incarnation of the Hindu god Vishnu --that will give India world leadership in science and engineering – and IT service work.

An essay by Murali (Murali 2003) in a recent issue of the Indian magazine *Frontline* offers a more tempered opinion. He describes IIT as an "island of undergraduate excellence … in an otherwise mediocre higher educational system." To start with, the cost to the student is about $1500/year compared to MIT's 2002-2003 room-board-tuition cost of ~ $38000. This seems very low, but it must be remembered that the average per capita annual income in India was a good deal less than a thousand dollars – roughly $800 -- at that time compared to a US figure of ~ $32000. Access to IIT education would therefore be much more skewed to the higher income groups of India than would be the case in the United States. There are usually large expenses associated with coaching and preparation for the JEE examination which

would be hard, if not impossible, for poorer families to meet. Next, there is severe

under-representation of women, "Scheduled Castes", and "Scheduled Tribes". (These

latter categories, an inheritance from the historically complex social structure of India,

refer, in a broad terms, to socially and economically depressed classes. It is not

necessary to go into this subject in any detail. The names alone imply the existence of

important social divisions.) While IITs reserve a percentage of seats for applicants from

the Castes and Tribes, they have difficulty filling even half of these quotas. The low

admission of women is said to be the result of social stereotypes that picture women as

mentally incapable of mastering the IIT curricula. Families are often unwilling to go to

the expense of preparing their daughters for the examinations, despite the refutation of

the stereotyping proven by the good performance of those women who have succeeded

in entering the IITs.

There is evidence of considerable migration of IIT graduates abroad. (A local

joke on the subject describes an IIT graduate as a man with one foot in India and one

foot in Air India.) Murali, (in the same article), while asserting that IITs do not collect

data on emigration of their graduates and also admitting that data are scarce,

nevertheless estimates that half of the undergraduates go abroad, mainly to the US, for

higher studies and about 80% of these stay permanently. He states that there are

about 25,000 IIT alumni living in the US. There are also complaints that many IIT

bachelor's degree graduates fail to pursue careers in their specialties and move instead

to more lucrative non-technical jobs. Further, he says, "The IITs involve a considerable

burden to the Indian taxpayer and this raises the important question of how the country

should direct its educational investment. In a country with a woeful primary education

record, government funding of the IITs is significant. " In 2002-2003, he continues, India

spent Rs. 5.64 Billion for IIT education of about 27,000 students and only Rs. 35.77

Billion for elementary education.[1] He observes, "… the allocation to primary education

is grossly inadequate … Is the right balance between primary and higher education

being maintained?"

(That said, as is the case with other nations striving to move into modernity, the

Indian government's investment in technological education plays a large role, and the

usual Ricardo-comparative advantage free-market model does not apply. What does

apply is that buyers of computer services will be attracted by lower prices, if offered, and

will have little or no concern about how these prices are being achieved.)

While India has made great progress, it is a mistake to think of the IITs as the

whole picture of its technological position. A *Newsweek International* article by Liu and

Mazumdar (Liu 2007) tells us that, while India produces about 500,000 technical

graduates per year, the head of the Indian software trade association NASSCOM,

states that only 25-30% of these are "suitable" (i.e., competent.) The authors report that

pay for university teachers is low and they are often lured away by the much higher

wages offered by private firms. There is a serious lack of highly trained people at the

Ph.D. level. India graduates only a small number of these, about what a tiny country

like Israel produces, as pointed out by Raghavan in an on-line Forbes column (8/13/07).

(Raghavan 2007). He reports that Indian industries and companies such as Infosys

(which is very active in seeking work in other countries) have resorted to in-house

training.   Raghaven also states that India has a chain of NIIT schools set up by India-

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[1] The *World Factbook* (Central Intelligence Agency 2011) estimates the Indian illiteracy
rate at 40%

based companies that offer training for IT jobs and also combines this with the sale of IT services.

V. The Argument That a Shortage of US Programmers Exists.

As has already been mentioned, there has long been advocacy of the ideas of a shortage of computer technologists. A prominent example of this position was that of Bill Gates in Congressional hearings (Gates 2007; Gates 2008). On those occasions he called for the United States to reform immigration policy to prevent the loss of "top" foreign experts to other nations, for foreign students upon graduating from U.S. colleges and universities are forced to return to their homelands because an insufficient number of H-1B visas is available to employers who wish to hire them. Further, he said "… we face a critical shortage of scientific talent....Our immigration policy is driving away the best minds exactly when we need them most."

As has been said already, Industry groups strongly advocate outsourcing methods whether by contracting abroad or by importing workers under the highly controversial H-1B visa program of which we shall say more later. Examples of such organizations and their viewpoints are Compete America and TechAmerica (Compete America 2011; TechAmerica 2011) Compete America is an association of 34 prominent companies (e.g., Boeing Corporation, Coca-Cola, Intel, Microsoft, etc.) and other institutions. The aims of the organization in the "Principles" section of their web site (Compete America 2011) are "to provide world-class education and training" (presumably to US nationals) and "to establish a secure and efficient employment-

based immigration system that welcomes highly educated and talented professionals to our nation." (Other wording of these statements has appeared, but the sense remains essentially the same.) The literature and actions of Compete America are not intended to be objective or scholarly. Rather, they consist of straightforward advocacy aimed at achieving as great an increase as possible to the numbers of foreign technical workers permitted to come to work in the United States. Thus, H-1B workers are characterized as expert specialists; the process of admitting H-1Bs and of issuing "green cards" to foreigners seeking permanent residence is described as unnecessarily slow; America is said to be backward in training engineers, scientists, mathematicians and IT workers. Also, Compete America's membership consisting of important companies should guarantee ready lobbying access to Congress and government agencies.

It is naturally the case that importing goods and services from other countries comes to be denounced in multiple ways by those who lose in the process – as unfair in one respect or another, as cutting into domestic production and siphoning off jobs to foreigners -- while those who gain from buying imports more cheaply than they can be had at home take a completely opposite view. Thus we find outsourcing of IT work defended in a document issued in October 2005 (Global Insight 2005.) This report, commissioned by the ITAA (Information Technology Association of America, now merged into TechAmerica (TechAmerica 2011) and written by the large economics consulting firm, Global Insight (HIS Global Insight 2011), has the general theme that savings that IT companies achieve by having work done overseas are multiplied into big increases in domestic employment, wages and GDP. The ITAA, now a leading

participant in an industry alliance, <u>TechAmerica,</u> is an influential association of a large number of leading industrial companies active in Congressional lobbying and in representing its views in the media. It claims that its membership "contains most all of the world's major ICT firms and accounts for over 90% of ICT goods and services sold in North America." (Other organizations now part of <u>TechAmerica</u> are the American Electronics Association (AeA), Government Electronics and Information Association (GEIA) which describes itself as representing high-tech industry doing business with the government, and the Cyber Security Industry Alliance (CSIA).

The report bears the lengthy title, <u>The Comprehensive Impact of Offshore Software and IT Services Outsourcing on the U.S. Economy and the IT Industry.</u> This 2005 document, for which only the Executive Summary is readily available, is a revision of a similar analysis published for ITAA in 2004. While the report has an appearance of the result of a technical investigation, it has an unmistakable, if restrained, tone of advocacy, e.g. benefits are said to "ripple through the economy" rather on the merits of outsourcing from the Ricardian concept of comparative advantage. The authors predict many large benefits from outsourcing to the U.S. economy. They say that outsourcing will result in over 337,000 net new jobs by 2010 and increase real GDP by $147.4 billion over the amount that would be generated if outsourcing of IT services does not occur. The effects of the savings resulting from the outsourcing of IT work are predicted to spread throughout the U.S. economy. The jobs of displaced domestic IT workers, it is said, will be absorbed by the new jobs created in other areas. A series of benefits including "job creation, higher hourly compensation, higher real GDP growth, contained inflation, expanded exports," etc.

are predicted. At the same time that this increase in outsourcing of IT services occurs, the authors claim that the "large and growing US trade surplus in services" – the summary does not tell what these services are -- will continue. (This assertion is rather puzzling, for one may wonder how it is that, for one set of services (IT), foreign countries have an advantage, yet at the same time the US has a "large and growing" advantage in other, presumably similarly sophisticated, services.)

The final section of the Executive Summary, titled "Conclusions and Recommendations," is markedly different in tone and character from the previous ones, and even possibly contradictory in some respects. For example, it is strongly recommended that efforts be made to increase the numbers of science, engineering and mathematics graduates both through government financial support and through presenting "a more positive image of the technology fields to increase student interest in math and science." The contradiction: if outsourcing as discussed previously offers the benefits described, why should steps be taken to increase the number of technologists if they are only going to be displaced later? Serious concern is also expressed over the fate of displaced American IT workers who would lose their jobs, and it is also suggested that the government should fund their retraining which also seems contradictory. There is also a call for increases in the number of visas for the admission of foreign worker specialists. The rationale for such actions may be that the authors feel, much as we have said in our introduction with respect to computer science and engineering, the national necessity to maintain and advance knowledge and research in science, technology and mathematics generally.

Finally, there are calls for improvements and enforcements in trade policy with the aim of removing barriers to US exports, "leveling the playing field" by insisting that countries that trade with us "adhere to labor and environmental standards similar to those of US corporations."

VI. The Argument That the Claim of a Shortage of US IT Workers Is False

The previous section has described the arguments asserting the claim of a shortage of computer technology workers together with advocacy of increased quotas for immigrant programmers. The largest numbers of these are commonly admitted to the United States under the H-1B visa system which has been subject to much, often fierce, controversy. In government documents, (U.S. Citizenship and Immigration Services 2011) the H-1B worker is described as "an alien admitted to the United States to perform services in a "specialty occupation." The rules for these visas are complex with many conditions, exceptions, alternatives, and ambiguities.   They are of particular interest here because their biggest application is to the admission of Indian "non-immigrant" computer workers. A surprising fact about these workers is that despite all the elaborate paper work that surrounds each worker's admission and therefore enable the number of petitions that succeed or fail to be exactly counted, the number of holders of these visas presently in the United States is known only as a rough estimate.

As has been said, this claim of a shortage has been regularly voiced by computer industry entrepreneur groups and their leaders. It is often implied that the

shortage of US information technology workers arises because Americans are not interested in careers in science, mathematics, or engineering, and, in any case, are professionally inferior to their foreign counterparts. (Gates 2007; Gates 2008). Such views as these have been strongly attacked in blogs and articles on the internet. Most of these can be characterized as being of the labor-movement type, complaints of greed and exploitation by employers of both US and foreign workers. These are often joined by those with overt anti-immigration sentiments similar to those of the long-ago "Know-Nothing" movement that surface from time to time in our national history.   An example of this position is exhibited in an issue of the _Phyllis Schlafly Report_ (Schlafly (2003). There, the admission of foreign IT workers is denounced in harsh language as a "scam," the companies who hire them are similarly castigated, and the H-1B program is a "government subsidy" to industry, an opinion often attributed to Prof. Milton Friedman.[2]   Such opinions, although expressed by a conservative organization like Ms. Schlafly's _Eagle Forum_ , are often indistinguishable from those of worker's groups, such as Compete American Workers.[3](Compete American Workers 2008)

There are many articles and comments denouncing the claim of a software labor shortage. The single most elaborate and thorough of these is to be found in the heavily documented and lengthy (112 pages) testimony (Matloff 1998) of Dr. Norman Matloff, professor in the Department of Computer Science at the University of California at Davis, before the Subcommittee on Immigration of the U.S. House

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[2] A search for a publication, article or paper in which the late Prof. Friedman might have made this assertion was unsuccessful. The claim of his sharp opposition to H-1B visas has been cited in many places but it is not possible now to verify it.

[3] No information was found concerning the history, present leadership, or number of members of this organization.

Judiciary Committee. Prof. Matloff's testimony and articles, whatever their accuracy on specific points, appear to have significantly influenced important senators such as Charles Grassley and Richard Durbin who have proposed important reforms of the H-program (Thibodeau 2009.) He continues to write forcefully on the subject. We concentrate on his testimony here not because we believe it to be correct or accurate in all respects, but rather because it is a broad discussion of the "anti-shortage" view.

Matloff's testimony dealt with three issues which are (1) claims of a high-tech labor shortage, (2) the H-1B program, and (3) difficulties faced by older tech workers. On the claims of a high-tech labor shortage, Matloff states that the claim really means that employers want to have applicants with _previous_ experience in specific programming skills. Such a demand, he says, is impossible to satisfy to the degree that companies would wish because the programming field changes rapidly and no matter how many graduates in the field are produced by colleges and universities, most of them, not even the most recent ones, will not have the latest skills. Additionally, he remarks, it is useless for older programmers to take classes to bring their knowledge up to date, because of that common insistence by companies on actual experience. The phrase "hit the ground running" was constantly used by recruiters in his conversations with them. Matloff further cites studies by the General Accounting Office, the Urban Institute, and UC Berkeley which fail to confirm the claim of shortage. Remarkably, studies by what he labels as "highly pro-business groups" like the National Research Council, the Department of Commerce, and the Computing Research Association likewise failed to support the idea of a shortage. In further contradiction of industry claims, Matloff has found that only 2% of programmer applicants are hired. If the

shortage is as "desperate" as claimed, he asks, why are the recruiters so picky? Moreover, as often claimed by others, and as my own examination of Bureau of Labor Statistics data shows, programmer wages have grown little, if at all, in excess of inflation. Thus, many, besides Matloff, ask rhetorically why the claimed "desperate shortage" does not result in the bidding up of programmers' wages. One might conjecture that their wages stagnate because of foreign competition in various forms, but this contradicts the idea of a worker shortage. Matloff adds examples of other professions, such as surveyors and dieticians, whose wages in the late '90s grew far more sharply than inflation.

Matloff discusses many other aspects of the shortage question besides these. In essence, his arguments come down to his statement "When the industry claims a shortage of programmers, what they mean is a shortage of cheap programmers."

The second issue is that of importation of information technology workers under the H-1B visa program. This program is one of over 30 types of "non-immigrant" visas that the US Citizenship and Immigration Service (USCIS) issues to foreigners who wish to enter the United States temporarily for various purposes. Of these, several are for those who come as "temporary" employees – a term that may refer to short periods or many years of residence. The H-1B visa is the one most commonly discussed. It is intended to be used for "specialty occupations" implying that the employee have "specialized knowledge," attainable with at least a bachelor's degree or an acceptable equivalent. It is based upon the already-mentioned assumption that there is a shortage of US citizens capable of filling such jobs, and that foreigners must be brought in to keep the employers' businesses running. Employees cannot apply for visas

themselves, but must be petitioned for by an employer. The number of such visas granted annually is limited by "caps" set in each fiscal year by Congress. Currently the limit is 65,000, but not all H-1B immigrants are subject to this. For example, institutions of higher education are exempt and an additional 20,000 new visas may be issued to admit those with Master's or higher degrees from a US institution. The law requires that the sponsoring firm attest that US citizens are not available to fill the position, and that the wages paid to the non-citizen will be the same as those generally paid. These are only a few of the many required conditions specified in this elaborate and complex law, overlaid as it is with *ad hoc* exceptions as well as many concepts and terms that can be subjectively or inconsistently interpreted. The many law firms that exist to sell legal counsel to both employers and employees attest to this; one may well suspect that violations are not uncommon and that enforcement is difficult or lax.

The 65,000 "cap" on H-1B visas is often misinterpreted to mean the number of H-1B workers in the United States. Rather it is a starting point figure for making an estimate – a difficult task, considering all the rules and exceptions – of how many alien "specialist" workers are admitted annually. It is surprising to find that despite elaborate paper work over the merits of work petitions, the concern that associated fees be paid, and the policy argumentation over how many visas should be issued, it is not known (North 2011) how many H-1B workers are, in fact, residing in the United States at any particular time. The only data available that is relevant to that is the annual number of H-1B petition approvals for initial and continuing employment. (A crude "back-of-the-envelope" calculation based on those figures gave an estimate of roughly 700,000 H-1B computer occupation workers, mostly from India.)

Matloff asserts that the basic assumption that H-1B workers are needed for lack of competent US programmers is false. The "hit the ground running" requirement is for US workers only – if they are considered at all – whereas the H-1B workers, far from being expert, are allowed to learn needed skills on the job. Employers often claim that they have urgent tasks that must be dealt with at once, but, he says, they are willing to wait for H-1B workers to learn because they work for less.   This implies that the requirement of the H-1B law of equal wages for the foreign worker – the idea of "equal wages" itself may well be interpreted ambiguously -- is being flouted. This is possible, it is claimed, because the foreign worker is afraid to complain lest he or she be blacklisted or sent home. (The immigration law firms themselves (Brown 2009) warn potential worker-clients to be very cautious in trying to press such charges.)   Additionally, a complaint to the Department of Labor will likely be useless because, he says, the Department itself complains that it is hamstrung by what Congress has written into the law itself from taking adequate action. Matloff characterizes H-1B workers as "indentured servants", under the thumb of their employers. This claim moves beyond mere assertion, for support for this view comes from actual court decisions against firms that forced H-1B's to sign illegally onerous contracts. For example, under the law, if an employee is "benched" – meaning that for some period they have no work for the employee – the salary must still be paid. Demonstrable incidents have occurred, however, of the sponsoring company attempting to force the worker to accept reduced wages or none at all.   Matloff remarks that discrimination against US citizens by use of H-1B workers is not a "natives vs. immigrants" issue. The discrimination is the same

whether the US citizen worker is a naturalized Indian or a native-born person of whatever ancestry.

Claims that H-1B programmers and IT workers get significantly lower wages than US programmers abound in discussions of foreign worker hiring. Prof. Matloff emphasizes this strongly. He cites cases of testimony before Congress by industry representatives claiming that they cannot find US workers and therefore the importation of more H-1B's is absolutely essential. At the same time, he reports, these same entrepreneurs have hired H-1B workers at well below average salaries. (This information was obtained under the Freedom of Information Act.) Thus, he cites H-1Bs as earning $30,000 to $43,000 in the Washington area (year 2000 figures) while an escalator mechanic on the DC Metro is paid $49,000 annually. Elsewhere he states that US "high-tech" employees' salaries are about 20% higher than those paid to foreigners. To support his "indentured servants" argument, he quotes the deputy administrator of the Labor Department's wage and hour division, who said that foreign workers can try to get fair treatment only by filing a complaint, an act which might severely endanger their prospects. Moreover, the law is sufficiently ambiguous that employers are very likely to argue successfully that they have acted legally. One important source of control over foreign employees is that they may well be in the position of requiring the co-operation of their employer to get a "green card". The "green card" affords the holder permanent residence (unlike the H-1B visa which would be valid for a maximum of 6 years) and is only acquired after a lengthy review as well as a lottery. The employee may well feel that if he or she should be considered "uncooperative," such as by making salary or working condition demands, the green

card approval process might be broken off and have to be resumed from the beginning, perhaps with another employer, or perhaps from overseas.

A particular feature of the H-1B visa system is the existence of "body shops." A "body shop" is a company in which more than 15% of its employees are H-1B's. The "body shop" commonly leases out its employees to other companies. Wages are substandard, and there are often cutbacks in wages when employees are "benched", that is when there are periods when there is no work for them. As remarked above, the Department of Labor has difficulty dealing with what are either illegalities or, if nominally legal, practices that circumvent the apparent intent of the law. (Accusations of "body shop" exploitation are not merely anecdotal, for prosecutions have occurred, sometimes successful and sometimes not.)

Matloff's third major issue with the claim of shortage relates to age discrimination and the difficulty of older IT workers obtaining employment. He concludes, mainly on the basis of reports of individual experiences obtained through conversations and correspondence, that the IT industry avoids hiring older employees not because they lack skills but because they would (presumably) demand higher wages than H-1Bs or very recent graduates. He finds this pattern of shutting out older programmers repeatedly among both IT executives and HR recruiters. A variety of rationalizations are used to justify this practice or even to deny it. A common industry assertion is that "hot skills" are what employers want, and older employees will not have them. In refutation, Matloff cites cases such as that of a programming expert with 20 years experience with a wide range of employers and current as well in more than the number of skills requested in a particular company's employment advertisements. The CEO of

that company had recently testified to the House Science Committee over his hiring difficulties, yet the applicant was not even called for an interview. In another case, the author of a well-regarded and then currently used reference work related to the UNIX operating system reported that he was not even considered for an entry level job.

It is not unusual to find that as employees in scientific and technical fields age, they leave the profession. This attrition is much sharper in computer sciences than it is in other technical fields. For civil engineers, for instance, Matloff cites data from a 1993 National Survey of College Graduates report that shows 52% of them are still working as civil engineers 20 years after graduation. For computer science graduates, the figure is only 19%. While Matloff's principal explanation for age discrimination, as has been said, is that younger workers work for lower wages, he observes that there may also be a cultural bias at work, that young managers – and most managers are indeed young – find it uncomfortable to supervise much older employees. An often-made claim, made sincerely or otherwise, that older employees with families are less willing to work long hours or with the intensity than young unmarried employees. Prejudice against older employees is often implemented by such tactics as computer scanning of resumes, so that the indication of an applicant's age over some arbitrary figure or a lack of "hit the ground running" experience with some skill causes that resume to be automatically tossed aside. These practices, when combined, give a false sense of the employment situation. Bureau of Labor Statistics do not report underemployment or losses to a particular profession. A bus driver or supermarket clerk who used to be a programmer-- and might be again if given a chance – is no longer an unemployed programmer, but

counted rather as an employed bus driver or a supermarket clerk, and artificial evidence of a shortage is thus created.

Professor Matloff is by no means alone in his contentions that the claim of a shortage of computer technologists is false (Galama 2008; Teitelbaum (2003). In a later section of this document, we shall discuss our own findings on the subject.

VII. Offshoring in Computer Work: What is and what is not happening in International Programming Service

One of the remedies for the alleged shortage is outsourcing of computer work to other countries where presumably enough technicians of high competence may be found at lower cost than can be hired domestically. (The analogy to Ricardo's wine/cheese example is obvious.) Certain types of offshoring work are commonly practiced nowadays. You may have, for instance, a question about your bank account or credit card and discover that the person helping you may be located anywhere, perhaps as far off as Mumbai.   As indicated previously, at the start of this study it was assumed that there was a similar system of trade in providing computer services that might be termed "arms length." An American company would, it was supposed, contact a foreign information technology company to contract having the work done <u>in the foreign country</u>. Communication, when needed, would be done remotely by phone or electronically.   Such a company might conceivably be one of the great Indian technology firms such as Wipro or Infosys.   However, there are serious drawbacks to such a proceeding, problems which turn up whether we are speaking of advertising,

accounting, animation, or any of the myriad other applications of modern computers.

First of all, there is the central problem in seeking offshore IT services: how can one select a company that is competent to do the work? What is the quality of their programmers ?   While India graduates as many as 500,000 technical personnel annually, only an estimated 25-30% are said to be "suitable". (Kiran Karnik, head of India's National Association of Software and Services Companies, quoted in Liu (2007)). An article in Information Week (6/5/2006) cites a Duke University study (Gereffi 2008) asserting that these large figures, both for India and China, should be understood to include many graduates of two- or three-year programs, with no standardization of degrees. This suggests that computer services have much of the character of a <u>non-tradable good</u>. The classic example of a non-tradable good is that of a haircut done by a Chinese barber in Beijing. Perhaps that service might be done far more cheaply and better done than in the United States, -- or perhaps not -- but clearly there can be no international trade in haircuts over the distances involved. Something similar occurs with computer services. The customer and the computer service provider must work closely with one another to make sure that they both understand what is needed before, during, and after the work is done. The customer and the IT worker may have meticulously planned beforehand what they want the software to do, but as the work progresses, unexpected problems will inevitably arise that both parties will have to overcome together. A common situation is the need to test the programming to assure that it will give the right answers when real users are submitting real problems. Imagine, for instance, that a bank wants to have a program that is to be used by the depositors to check their various kinds of accounts via the telephone or the internet.

Will the software be helpful and practical, or will it simply annoy the bank's customers who will demand to talk to a human being instead?

Another common situation is for an engineer or physical scientist to take his/her equations to a programmer for the calculations he/she wants done. They collaborate in deciding the methods. The scientist may propose tests to see whether the program gives correct answers to known problems. The methods they originally started with to attack the problem may prove unduly slow or not work well. Such issues have to be resolved by working and debating together daily, even hourly.

Outsourcing work, whether offshore or domestically, presents other problems as well. The client and the vendor have to have a contract that explains what each expects of the other so that a relationship of mutual trust can be established. An article published in the MITSloan Management Review (Barthélemy 2008) describes the experience of a French IT company that first found its standard contract insufficiently detailed, with the vendor constantly claiming charges for services not covered. The company then substituted an exactly detailed contract with a different vendor, only to find that it worked equally badly by generating suspicion between the parties over company micromanaging demands for penalties. Vendor resentment rose, as did uncooperative behavior and increasingly poor performance.   Then (with a third vendor), by adopting what Barthélemy calls "The Goldilocks Strategy" -- recognition of the need for flexibility in the face of inevitably changing conditions and the fostering of collaboration and trust by using special joint committees to continuously work out problems -- success was achieved in the form of large cost savings and excellent vendor performance.

A number of other problems have turned up in anecdotal reports of relations between Indian vendors and their American or European clients. One of these is the obvious problem of distance, compounded by a time of day difference of many hours with the United States. Thus 9 AM - 5 PM, Monday, EST, US corresponds to 10:30 PM, Monday, - 6:30 AM, Tuesday, in India, with a corresponding awkward displacement of 9 to 5, Monday, in India corresponding to 7:30PM, Sunday– 3:30 AM, Monday, EST, US. Next, there is a problem of verbal communication. However well an Indian may know English grammar, syntax, and usage in <u>written</u> form, the <u>speech</u> of the Indian, affected as it is by the many native languages of the subcontinent, is different from that of other Anglophones, and more so than the degree of differences between, for example, the dictions of Australian, British, and American speakers. Long hours on the telephone are the consequence. Differences in social mores also cause difficulty. It is frequently claimed, for example, that India has a culture of friction avoidance that is carried to excess – there is a perception that difficulties that arise are minimized or mention of them is avoided. There is also a matter of social stratification – the "Scheduled Castes" and "Scheduled Tribes" mentioned earlier are examples – that can raise personnel problems, and may not be well understood or accepted by Westerners, even if their societies have their own varieties of this condition.

To sum up, "arms length" provision of computer services, which was the model we initially supposed, has these drawbacks:

1. The customer will have difficulty assessing the competence of the overseas provider of computer services.

2. Satisfactory results in doing computer work depend on a close relationship between the customer and the programmers. Physical separation between the two will give many computer services the character of a non-tradable good.

3. The customer and the IT service provider must come to specific agreement about what the task is supposed to accomplish. Such agreements often prove troublesome to maintain since, in computer work, adjustments will almost inevitably be found necessary. The difficulties of satisfying contractual obligations will be magnified by physical separation between the parties.

4. Cultural differences in behavior and language usage breed misunderstanding detrimental to the success of the job at hand.

It should be noted however, that not all overseas relationships in IT fail to work. An important case is that of the sale of software packages that are used to do particular jobs. American companies, for instance, could successfully export software like the WORD or EXCEL programs abroad and analogous importing of codes from other countries can exist. This trading does not involve close personal collaboration in the creation of the package between the program vendor and the user/customer. However, as anyone who has had to wrestle with the vagaries of the two program packages mentioned knows, the closer "help desks" for such products are to the user, the better.

The difficulties of offshoring have been the subject of various anecdotal articles . Others in praise of offshoring computer work have been issued as well. The fact is, however, that, in a remarkable development, both Indian and U.S. companies that provide computer services have chosen to set up business in each other's country and thus overcome the problem of distance between the client and the vendor. This

development convinced us that our initial impression of US firms sending computer business overseas was wrong. In a free market system, firms change their business model to suit circumstances. In this case, close contact with customer has been recognized as more likely to be profitable and efficient than "arms length" practice. Moreover, American firms are motivated to operate in India and other Asian countries in (Rai, A. 2010) order to establish footholds in growing, and therefore potentially profitable, markets. IBM is a notable example of this, and speculations have been made in Indian press articles that the number of IBM employees in India is as many as a "lakh," the Indian name for 100,000, and even that IBM is the second largest private employer in that country. (Associated Press 2011; Rai. 2010; IBM 2010). Intel and other companies have also made significant moves, but apparently not to the same degree. Analogously, Indian companies like Wipro and Satyam have also moved to seek business in the United States. Thomas Friedman's "flat world" (Friedman 2005) concept notwithstanding, at least one important difference exists: American companies hire local technical talent in India, whereas Indian companies that have come to the U.S. tend to employ Indian nationals. It is harder to get an American to work in India than to persuade an Indian to work in the United States.

Unfortunately, we are unable to cite statistics on the amount of such operations in terms of dollars and number of employees. In their advertising, all such companies emphasize their international character, often citing long lists of their external subsidiaries in famous world cities as well as "case studies" of claimed successes with unnamed clients. Hard numbers about profits, losses, and investments are discussed in generalities or treated as "proprietary" and thus not available. All that can be said is that

these country-to-country movements exist and that it appears that offshoring computer work is being transformed to <u>local</u> outsourcing. Although the vendors may be of foreign origin, and in competition with local companies as well, the market in which they do business is quasi-domestic, not one of export/import trading.

VIII. The World Position of the United States as a Source of Graduates in Computer Science and Other Branches of Technology

Industry advocates in the United States, we have said, regularly warn that the United States is falling behind in competition with other nations because of a claimed lack of interest in America's youth in science, mathematics, and engineering. Supposedly, US students are "turned off" by the difficult course work that is required to obtain professional-level education in those fields. Besides Bill Gates, well-placed figures such as Paul Otellini, CEO of the Intel corporation and Carly Fiorina, former CEO of the Hewlett-Packard corporation, are quoted (<u>McCullagh</u>, 2010) as advocating as a <u>necessity</u> the importation of foreign IT workers into the United States to make up for this perceived weakness. Along with a series of claims of government mismanagement of immigration, it is said that the United States, once the world leader in the IT field, is so no longer.

Publicly available information begins to give a different picture of the matter. Table A-1, dating from 2004, is a modification of one issued originally by the Organization for Economic Cooperation and Development (OECD.StatExtracts (2006 and 2010). The table lists the <u>percentages</u> of the total number of graduates (second column) in computer science. The next column lists the percentage of the total number

of graduates in other technological fields and the last column lists the percentages for non-technical fields. These two columns are the result of our merging columns of more detailed data in the original table. This table has been sorted from largest-to-smallest in the list of percentages in the column of computer science graduates. In this ordering, the United States ranks as 15th on the list, seemingly well behind countries like Australia and Mexico in fostering technology, and thus appearing to validate the claim that the United States is falling behind in producing graduates in the field of computer science. However, in Table A-2 we have listed the number of graduates in each field and each OECD country by multiplying the percentages by the total number of graduates in the second column, and a totally different impression results. When the table is sorted in order of the number of computer science graduates, the United States is the leading country by far, producing 38% of the total number of those graduates, with the number of US graduates being approximately the sum of those of the next four nations. It is true that there are indeed problems with the accuracy and consistency of the figures. The various countries reported both what and how they wished to report. For instance, the data for Japan did not explicitly specify the number of computer science graduates, and the figure shown in our table is, we hope, a reasonable estimate. Further, examination of the source of the data for United States computer science graduates show that computer hardware engineers were not included, but we cannot tell whether other countries did the same.   We do know that 2004 was a peak year for the number of US computer science graduates. (Fig. B-1) This plot (OECD.StatExtracts 2006 and 2010) shows a substantial fall off after 2004 in the number of computer science graduates for Bachelors and Masters degrees. The variation of the relatively small number of doctors

degree graduates compared to the others is concealed as plotted on the left hand vertical scale of that figure, but when shown alone on the right hand scale, a sharp and substantial rise in their number becomes evident, and contrasts strongly with the fall off in the others after 2004. Moreover, year by year data for OECD nations shows that the United States was still in the lead in generating such graduates. In Fig. B-2, where a comparison is made between the United States, Japan, and Germany of the number of all engineering graduates, the same kind of dominance is evident. Japan and Germany show growth, but at a rather modest pace, while the numbers for the United States shows a strong upturn during the last half of the decade.

Additional data from the OECD statistics tables (OECD.StatExtracts 2006 and 2010) and other sources, which we now discuss, tells us, in blunt terms, that the United States is a technological and industrial giant among the nations. Much is made, for example, of the large overall trade deficit. Indeed, the trade deficit is undeniably a significant problem, but attention is seldom drawn to the sharp rise in US exports, (shown in the graph of Fig. B-3,) that has accompanied this deficit. Notable among US exports are machinery, electrical machinery, vehicles, aircraft and medical instruments, high value agricultural goods, and services. (Answers.com 2011; U.S. Bureau of the Census 2011). In one trade category, that of services, Fig.B-4 shows the not well-known fact that the United States has even been running a well-maintained surplus of exports over imports for many years. An interesting statistic is the following. The value of U.S. service exports in 2008 was about $546 billion dollars; that of India, which has been expanding at a much noted high percentage rate in recent years, was $102 billion dollars. (Trade Map 2011)

The OECD statistics show the unequivocal U.S. leadership and its vigor. The

OECD is an institution that represents 34 nations of the "first world" of industry and

technology.   It includes 22 of the 27 members of the European Union plus several

major non-European nations, among which are the United States, Japan, Korea and

Mexico. The United States population is about 26% of that of the OECD total. All of the

important categories that we have examined of the various fields of science, technology,

and education, and indeed in computer technology itself, confirm this leadership status.

It is rarely, if at all, alluded to in the disputation over whether a shortage of computer

workers – and for that matter, in technology fields in the United States generally – exists

and thus may require action such as increasing the number of foreign workers allowed

to enter. Examples are the following, all obtained from OECD.StatExtracts for 2008, or,

if earler, the latest reporting year:

1. US graduates in Physical Sciences, 32,637 or 21.0% of the OECD total;

nearest competitor, United Kingdom, 19,436 or 12.5% of the OECD total.

2. US graduates at tertiary and advanced research program level in all fields of

study, 2,343,517 or 30.3% of the OECD total; nearest competitor, Japan,

671,064 or 8.7% of the OECD total.

3. US graduates at upper secondary education level, 3,321,520 or 26.4% of the

OECD total; nearest competitor, Japan, 1,172,879 or 9.3% of the OECD total.

4. US graduates in advanced research programs in engineering, manufacturing,

and construction, 8,366 or 27.7% of the OECD total. Nearest competitor, Japan,

3636, or 12.1 of the OECD total.

5. Classroom teachers and academic staff for tertiary and advanced research programs, 714,425 or 32.2% of the OECD total for 2001 Nearest competitor, Japan, 292,679 or 13.2% of the OECD total.

6. US graduates in advanced research programs in computing, 1698 or 28.5% of the OECD total. Nearest competitor, United Kingdom 706 or 11.9% of the OECD total.

7. U.S. enrollment of foreign students, 624,474 or 22.4% of the OECD total. Nearest competitor, United Kingdom 462,609, or 16.6% of the OECD total. (There is some inconsistency in the reported data.)

An approximate "productivity index" of these results can be calculated by dividing each of the percentages of the OECD total in the above categories by the percent of the total OECD population represented by each nations population.   The population percents are 26% for the United States. 10.8% for Japan, and 5.2% for the United Kingdom, the latter two being the "nearest competitors" in the 6 examples above. These "productivity indexes" are as follows:

1. Physical Science: U.S., 0.83; United Kingdom, 2.40

2. Tertiary and Advanced Research level graduates: U.S. 1.18; Japan, 0.81

3. Graduates at upper secondary education level: U.S., 1.03; Japan, 0.861

4. Graduates in advanced engineering research: U.S., 1.08; Japan, 1.12

5. Classroom teachers and academic staff: U.S., 1.70; Germany, 1.23

6. Graduates in advanced research programs in computing: U.S., 1.11, United Kingdom, 2.27

7. Enrollment of international students: U.S., 0.86; United Kingdom, 3.19

This listing shows that the U.S. production of graduates in research and technology, including computer research (the computer scientist category of the Bureau of Labor Statistics) is approximately consistent with the population standing of the United States among the OECD nations. That is, the United States is the single most populous nation in the OECD, and therefore would be expected to be represented by large numbers in all categories. The index tells us that the dominance of the United States in the OECD statistics is not solely the result of population, for the index, crude as it may be, also indicates that the country is able to keep up its human resources not only in computer science but in other kinds of technology as well.   (It is rather surprising that the indexes for Japan, a country notable for large numbers in the OECD statistics in all categories should show indexes less than 1, while the United Kingdom, not thought of as prominent, shows indexes here greater than 2.   However, the United Kingdom numbers are not the result of the "small denominator" effect, often seen in analyzing per capita figures or percentage production changes, in which data of small countries or changes in productivity of low level producers are made to appear excessively significant. The absolute numbers for the United Kingdom are sizeable and realistically impressive.) The OECD data shown above for graduates in the computer field refers only to those graduates who obtain advanced degrees and who aim for careers in research in either industry or universities. The OECD data does not explicitly cite information for the other kinds of computer workers, but the comparisons shown above for science, engineering, and education generally suggest that a comparison of other levels of computer workers would show the same kind of leadership position. (After all,

the numbers of Ph.D. graduates originated from a much larger field of those with Bachelor's degrees.)

A highly important factor in the production of graduates in technology in the United States is the large influx of foreign students who come for advanced studies _and who remain in the United States after graduation._ This fact throws the view of immigration of computer workers and other technologists into an entirely different perspective. Finn (2010),citing a report by the National Science Board, states that "the foreign born make up about 40% of the science and engineering work force with doctorates." The aim of Finn's study was to determine whether the stay rate of foreign doctoral students, which contributed to part of that fraction of the work force, was declining or not. (On this point, his report appears to be inconclusive.) His stay rate figures are nevertheless impressive. From his detailed and elaborate findings, a few samples may be cited to illustrate the phenomenon. Ninety-two percent of the over 2139 Chinese students (these, incidentally, were the largest national group of doctoral recipients of the 7850 total of foreign-born graduates) who graduated in 2002 were still in the United States in 2007. Similarly 81% of the 615 Indian graduates of that year were still here 5 years later, and of the total of all such graduates, 62% were remaining in 2007. Galama and Hosek (2008) make corresponding observations, as well as comments on the possible relationships to wage levels and the labor shortage question.

The rise in the percentage of all science and engineering doctorates might appear to give support to the idea that U.S. students are becoming progressively less interested in those fields. This viewpoint is mostly expressed _qualitatively_ and in that way more easily makes rhetorical points. Examination of actual data makes that view

less convincing. Fig. B-5 shows the number of doctorates awarded, 1987-2007,

displaying data taken from Finn (2010). It is true that the fraction of degrees granted to

foreign students is seen to be steadily increasing, but the number of degrees won by

U.S. students is not flagging and still substantial. The increase in the non-citizen

numbers reflects the dynamism of rising new economies involving literally billions of

people, but that does not prove that the U.S. economy is decaying. The migration to the

United States of young students seeking opportunity not only in finding jobs here, but

also starting their own firms, more than suggests the opposite. The facts brought forth

in this section offer no discernable justification for a claim that there exists a worker

shortage in computer science, or in other technologies, brought on by the U.S. economy

becoming too senescent to produce the high-quality manpower needed to "compete."

IX. The Wage Status, Employment/Unemployment Data, and Real Wages over Time of U.S. Computer Workers.

"If more computer programmers are needed to run Internet businesses,
the price of computer programmers (their hourly wage) will tend to rise.
The rise in relative wages will attract workers into the growing occupation."
                                    – Samuelson & Nordhaus, (2000), p.27

As already mentioned the wage question has been raised in connection with the claim of a shortage of computer programmers. Both employed and unemployed computer technologists argue that if a shortage truly exists, then wages offered should be rising, and then assert that they are not. The claim of a shortage is only an excuse, it is said, for the importation of cheap foreign labor, that the only shortage is of workers willing to be hired at low salaries. We shall consider wage and employment data not only for computer workers generally, but for the several different types of computer workers as well. Data for other occupations are also included to seek comparisons that may help illustrate such relevant employment features as worker shortage and economic stress due to competition.   Among these are registered nurses, physicists, college-level teachers of computer science, financial analysts, and even the seemingly distant job of a cloth and fabric patternmaker.

Most of the wage data we shall show comes from US government websites, primarily that of the Bureau of Labor Statistics (abbreviated as BLS) (BLS 2009) for the most recent available data, and at BLS (ARCH) for data from earlier years.

As is commonly known, the field of computer technology changes rapidly. Every owner of a personal computer comes to feel that the machine he or she bought two years ago is now "old hat." Objective support for that notion comes, for example, in the

shape of continually issued notices over the internet of software revisions to one's

machine's system or signals from web sites often accessed that they are now organized

into new versions which the user must download at once. Therefore, the time period of

discussion of wages has been restricted here to the past ten years, that is from 1999 to

2008 or 2009. This is done to preserve, as well as one can, consistency in the way in

which data on employment and wages is arranged and reported.

Table A-3 gives an overall picture of wages in computer technology and

illustrates some of the problems of accessing data. In the first column, I have given

brief names for the various occupations. I have substituted these for the lengthier

versions used by the BLS. In the second column is the Standard Occupational Code

(SOC) number used by the BLS to give a numerical designation for the occupation.

These numbers correspond to the BLS job titles. The third column gives the estimated

number of persons employed in that occupation.[4] The annual mean wages listed in the

fifth column is again an estimate of the arithmetic mean wage, the total sum of wages

paid in the occupation divided by the number of those employed. The median wage

column is the wage that is greater than or equal to the wages earned by 50% of the

workers in that occupation, or what is the same, the wage less than or equal to the other

50% of the workers. The two percentile columns listed indicate that 75% or 90%

respectively of workers earn less than that wage and 25% and 10% earn more than

those figures. (I have omitted the 10% and 25% data for brevity.) The SOC designation

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[4] These are estimates prepared from surveys, and the number of significant figures
shown cannot, of course, represent the much lower actual precision. Rather, this is a
way to label the numbers, a usage often followed in engineering calculations to avoid
ambiguities

of 15-0000 has a total of 16 occupations, including 6 mathematical occupations such as mathematicians, actuaries, and statisticians who are only indirectly involved in computer-related work. The important computer-based occupation of hardware engineer, listed in Table A-3 above is not listed by the BLS under SOC 15-0000 but rather under the 17-0000 group consisting of various engineering professionals. These arbitrarily set designations are altered from time to time, a fact that the user of the data needs to be aware of. In this instance, the omission of mathematicians, actuaries and statisticians does not cause much of a perturbation, because their numbers are a small fraction (1.26%) of the total and their wages are typical of those of others in the 15-0000 group.

In Table A-4, the 16 occupations the BLS has designated under the 15-0000 designation are listed. The wages of those working in the general computer field are much higher than those of the average worker. The median wage of $71,270 for 2008 is only a little less than the 90th percentile for all occupations. Even higher wages among the 15-0000 occupations are those of SOC 15-1011 (research computer scientists, median annual wage $97,970) and that of $97,400/year for computer hardware engineers (SOC 17-2061).   Workers in these groups are among the best educated in the profession. The lowest wage group is 15-1041, "computer support specialists", numbering 545,520 (16.5%) who earn a median annual salary of $46,370, somewhere between the 50% and 75% percentiles of all occupations.   (A complete description of what 15-1041 workers do, and for other SOCs as well, is given in the *Occupational Outlook Handbook for 2010-2011* (OOH 2010) which may be consulted (or downloaded) on-line.) Their most familiar image of the 15-1041category is that of

the "help desk" technician who answers phone calls from those seeking help with some computer problem. However, some of them may perform more advanced tasks such as running or testing software that has given trouble. The education required may be a bachelor's or an associate's degree, or, quite often, the worker may be entirely self taught and have no formal computer science education. Tables like this one for other years are much the same, showing a similar advantaged position on wages for computing technology workers compared to workers generally.

We have examined the change over time of wages paid to computer workers of the several specialties listed by the Bureau of Labor Statistics and compared them with similar data from other professions. The charts which we show here are of nominal and real (that is, "inflation corrected") wages paid during the decade 1999 -2009. The real wage has been obtained from the nominal median wage by the usual process of dividing the nominal wage by the Consumer Price Index/100. The Consumer Price Index values, commonly called the CPI, are normalized to a value of 100 for the year 1982. (Over this decade, the year by-year variation of the CPI has been strikingly linear. A least squares regression fits it almost exactly.) Table A-5 lists the occupations that were examined and the changes in real wages over that period.

Fig. B-6 shows the wage earnings of "all workers", i.e. the average wage-earner. The nominal median wage falls between 2000 and 2001 and does not attain the 2000 value until about 2004. The real median wage never recovers. A least squares line on a logarithmic plot between the relative flat portion from 2001-2008 shows the real wages of workers as a whole decreasing at a rate of - 0.3 %/year. Computer workers do better as a group. Fig. B-7 and Table A-5 shows their real wages rising at about 0.66%

year for a total of 6.1% over the whole period   In Table A-3, it is seen that a certain

fraction of the over 3 million computer workers does significantly better. Computer

scientists (SOC 14-1011) and computer engineers (SOC 17-2061), member of groups

which one can characterize as "elite," had median nominal annual wages in 2008 of

about $97,000 compared to the $73,000 level of the larger group of programmers (SOC

15-1021) The real wage of both computer scientists and computer hardware engineers

rose at about 1.9% and 1.5% per year from 1999 to 2008, for a total increases of 18%

and 14% respectively.   Fig. B-10 clearly shows the income gap between the scientists

and the programmers.

Fig. B-9 gives indications of the number and wages of computer science

educators teachers compared with computer scientists, but the picture is uncertain

because the academic year is 3 months shorter than the year of other workers. If the

numbers for teachers are multiplied by a 12/9 ratio, the wages come out approximately

the same, assuming that teachers can earn comparable wages.in the summer period.

The number of teachers rose from 2000 to 2005 and then fell off by about 10% from

2005-2008.

In Fig. B-11, an interesting phenomenon shows up in the case of computer

hardware engineers. After 2005, the number of these engineers drops off significantly.

In fact, the BLS occupational handbook (OOH 2010) warns that future employment

prospects for them are not as good as they once were. (It is not clear what the basis for

this assertion is.) Yet the wage over this recent period has continued to rise, seemingly

uninterrupted. This is illustrative of a "sticky wage" situation and also a counter-

indication of a shortage in an "elite" category of computer worker. This may also relate

to the rising unemployment that occurred during that latter period, which is illustrated in Fig. B-12. Unemployment fell off strongly between 2002 and 2007, and rose again sharply for all professionals, including computer workers and the architect/engineer group. Sharp as this decline was, it was only about half of what the general population suffered.

Fig. B-11 suggested a "sticky wage" as employment fell. Fig. B-13 shows the opposite case, exhibited for physicists, another "top" technological group. "Elite" status in a technological job does not necessarily go with fast growing income. Physicists (SOC 19-1031) have a high real wage, about 10% greater than computer scientists. The number of physicists rose strongly over the decade, but as the figure and Table A-5 show, the real wage for physicists, while relatively high among technologists, rose less that 0.9% per year, and the real wage line is almost flat.

Comparisons with yet other groups – we examined more than are shown here – were made to see if a connection between wages and worker shortage could be seen For example, financial analysts are often popularly considered as enjoying huge incomes. The real wage of that group rose at about the same rate as that for computer hardware engineers, or 1.6% per year for a total of 15% for the recent 10-year period. The real wage itself for financial systems analysts was about $10,000/year less than that for the engineers, illustrating that care must be taken in considering percentage changes calculated by the usual arithmetical procedure of "100 times (final – initial)/initial." The lower/higher the absolute level, the larger/smaller, generally speaking, the percentage is likely to be. (In the same way, emerging economies often exhibit very large percentage increases in gross domestic product in the early stages

because "initial" is of course very small for a poor country that is improving itself. By contrast, wealthy nations' show much smaller percentage changes even when the absolute change from one year to the next may be huge by comparison with that of a poor country.)

Fig. B-15 is a study of the nursing profession. The literature covering nurses is quite as disputatious as that for computer programmers, and just as many faceted. There are calls for the importation of non-citizen nurses to relieve a "shortage," -- the idea of a nursing shortage is conventional wisdom – yet one can easily find complaints by recent nursing graduates that they cannot find jobs. Importation of foreign nurses occurs from time to time – and then suddenly falls off. The graph, with its BLS numbers shows that the number of nurses employed is rising and their salary is growing, but how these numbers play out in the circumstances of real hospitals is not clear. An important feature is that the job of a floor nurse is quite tough, and they tend to try to move into administrative jobs which are physically easier and pay better, suggesting that perhaps the growth of salaries and numbers is reflective of that.

Our last example is taken from the garment industry in the United States. The Bureau of Labor Statistics 2010-2011 handbook of occupations estimates that employment in the garment industry will continue to fall sharply, and predicts that the number of employees in this occupation will fall by ~ 27% over the next 10 years.   Yet, as this plot shows, the real wage of this occupation has risen very sharply over the past decade, much more so than any occupation that I have examined. The nominal median wage rose by 77%, the real median wage rose by 37%, while the number employed fell by 61%. This observation – a continuing phenomenon, and not at all short term in

nature – is seemingly paradoxical since fabric and apparel manufacture is a contracting industry in the United States. However, the work of these patternmakers is essential to the functioning of any firm in that field. Although the number of firms in the garment business has severely contracted because of foreign imports, there is still a niche for better quality, more expensive clothing. This seems to be the one example of a shortage driving a wage increase that has appeared in this study. The job is essential, it is becoming more and more complicated, it does not pay well in the first place. Therefore, raising the wage to attract workers is an easy tactic.

X. Concluding Remarks

The original incentive for this study, the idea that computer jobs and work were to be transferred overseas does not seem to be justified because of problems associated with managing the successful accomplishment of computer tasks. Instead, an entirely different phenomenon is occurring, related to the idea that computer work resembles a non-tradable good. The programmers and computer technicians work best in close contact, and American companies, such as IBM and Intel have made significant efforts to move into Asian countries to capture a growing market in computer services. In the same way, Indian companies have established themselves in the United States for the same purpose. Unfortunately, data on whether these moves have been profitable is not available. However, even without such data, it is clear that much money has been invested in both cases. Both Indian and American companies try to take advantage of the wage difference between the two countries. Also of importance is

that Indian companies feel that they can work more efficiently with Indian workers. Indian citizens are very amenable to moving to the United States, while Americans are largely reluctant to move to India. At the same time, just as predicted in elementary theory of foreign trade, the wages of Indian workers have been rising. US wages in the field, on the other hand, seem to show a Keynesian "stickiness." The claims by computing technology industry leaders that there is a "shortage" are definitely belied by this. Comparisons of wage behavior to occupations such as nursing, where a need for more professionals is common knowledge show that wages do move. (Admittedly there are complications concerning that profession as well.)

Another aspect of the "shortage" are the figures that appear concerning the technological status of the United States among "first world" nations. The comparisons with OECD nations give powerful evidence of the leadership of this country both in number of graduates in technology, the level of their education and the competence that comes with it. Moreover, the United States is a magnet for foreign-educated technologists who seek both advanced education here and the opportunity to enjoy a life style much better than is possible in emerging economies such as India. Added to this is the entrepreneurial activity that Indian immigrants have demonstrated. For that reason, claims of a "lack of interest" among our students become either exaggerated or remedied by the influx of foreigners – "them" becomes "us" in the long tradition of our history.

The behavior of the industry in claiming a shortage of computer workers is questionable. Arguments laced with words like "desperate" do not appear convincing when there is no sign of wages in the profession soaring. Moreover, the demand that

new employees be able to "hit the ground running" and the rather relaxed process adopted in hiring do not add to a sense of alarm. Further, computer science is reputed to be a "young man's field" and one may well suspect that "ageism" is common. It is certainly true that a worker who loses his job in that field will very likely never be able to return to it. These are serious social problems, but it is not at all clear that they can be dealt with constructively.

References

Aspray, W., Mayadas,F., & Vardi,M., Editors, Globalization and Offshoring of Software, (2006); <http://www.acm.org/globalizationreport > [Accessed 2/23/2011]

Associated Press (2011), "About 1 in 5 IBM Employees Now in India," retrieved from <http://www.accessnorthga.com/detail.php?n=205230> [Accessed 4/4/2011]

Barthélemy, J. (2008), "IT Outsourcing: The Goldilocks Strategy", *MITSloan Management Review,* 12/14/2008 retrieved from <http://sloanreview.mit.edu/executive-adviser/2008-6/5062/it-outsourcing-the-goldilocks-strategy/> [Accessed 4/4/2011] (Also published in the *Wall Street Journal*, 12/15/2008)

Broad, W.J., Markoff, J., & Sanger, D.E., "Israeli Test on Worm Called Crucial in Iran Nuclear Delay," (15 January 2011) *The New York Times*, p. A1

BLS (2009), Bureau of Labor Statistics National Occupational Employment and Wage Estimates retrieved from < http://www.bls.gov/oes/current/oes_nat.htm>

BLS (ARCH), Bureau of Labor Statistics Archived OES Employment and Wage Estimates retrieved from <http://www.bls.gov/oes/oes_arch.htm>

Brown, M. F. (2009) "Things to Consider Before Filing a Department of Labor (DOL) Complaint for H-1B Wages" July 20, 2009, retrieved from <http://www.h1blegalrights.com/?p=291> [Accessed 5/5/2011]

Center for Immigration Studies (2011); retrieved from <http://www.cis.org> [Accessed 3/9/2011]

Central Intelligence Agency. (2011). *The World Factbook*, accessible online. <https://www.cia.gov/library/publications/the-world-factbook/index.html>

Clegg, Alicia (2010), "A Matter of Interpretation" *Financial Times,* February 2, 22:11

Compete America (2011) web site: <http://www.competeamerica.org> [Accessed 4/01/2011]

Compete American Workers (2011) web site <http://www.competeamerica.us/>

Course VI Undergraduate Programs, Department of Electrical Engineering and Computer Science (2010), Massachusetts Institute of Technology, Boston, MA <http://www.eecs.mit.edu/ug/programs.html>   [Accessed 3/31/2011]

Elwell, C.K. (2008) The U.S. Trade Deficit: Causes, Consequences, and Cures, Updated January 25, 2008, CRS Report to Congress, Government and Finance Division

Finn, M.G. (2010) "Stay Rates of Foreign Doctorate Recipients from U.S. Universities, 2007", Science Education Programs, Oak Ridge Institute for Science and Education. January; retrieved from <http://orise.orau.gov/files/sep/stay-rates-foreign-doctorate-recipients-2007.pdf> [Accessed 4/14/2011]

Friedman T. L. (2005), *The World is Flat: A Brief History of the Twenty-First Century*, New York: Farrar, Straus, and Giroux

Galama, T. & Hosek, J. (2008) *U.S. Competitiveness in Science and Technology* Santa Monica, CA : RAND Corporation; retrieved from <http://www.rand.org/pubs/monographs/MG674.html>

Gates, W. (2007) "Strengthening American Competitiveness for the 21st Century" <http://www.microsoft.com/Presspass/exec/billg/speeches/2007/03-07Senate.mspx> [Accessed 4/01/2011]

Gates, W. (2008) Testimony before U.S. House of Representatives Committee on Science and Technology, March 12, 2008, retrieved from <http://www.networkworld.com/news/2008/031208-gates-testimony.html> [Accessed 4/01/2011]

Gereffi, G., Wadhwa, .V, Rissing, B., Ong, R. (2008), "Getting the Numbers Right: International Engineering Education in the United States, China, and India," *Journal of Engineering Education*, January; retrievable from < http://ssrn.com/abstract=1081923>

Global Insight (2005) *Executive Summary: The Comprehensive Impact of Offshore Software and IT Services Outsourcing on the U.S. Economy and the IT Industry* (Document sponsored by Information Technology Association of America.) Lexington, MA: Global Insight (USA) Inc.; retrieved from <http://www.ihsglobalinsight.com/MultiClientStudy /MultiClientStudyDetail846.htm> [Accessed 4/02/2011]

H-1B Visa (2011) Workpermit.com, retrieved from <http://workpermit.com/us/us_h1b.htm>   [Accessed 2/28/2011]

Hart, K. (2008), "Gates Calls on Congress for Science Education, Visas." *The Washington Post.,* March 13 retrieved from <http://www.washingtonpost.com/wp-dyn/content/article/2008/03/12/AR2008031202216.html> [Accessed 3/8/2011]

IBM (2010), "IBM is India's second largest pvt sector employer," *The Times of India*, August 18 retrieved from ,<http://articles.timesofindia.indiatimes.com/2010-08-18/india-business/28286029_1_ibm-daksh-ibm-s-india-ibm-spokesperson> [Accessed 4/4/2010]

IES (2011) National Science Foundation/ National Center for Education Statistics, US Department of Education Sciences, accessed from <http://nces.ed.gov [Accessed 4/8/201]

IHS Global Insight (2011) accessed from www.ihs.com/products/global-insight/index.aspx?pu=1&rd=globalinsight_com [Accessed 4/02/2011]

Indian Institutes of Technology (2008). Wikipedia, retrieved from <http://en.wikipedia.org/wiki/*Indian_Institutes_of_Technology [Accessed 4/1/2011]*

Information Acceleration (1994) Oak Ridge National Laboratory Review (Vol. 25, Nos. 3 and 4), < http://www.ornl.gov/ORNLReview/rev25-34/contents.html> Chapter 3, retrieved from <http://www.ornl.gov/ornlhome/ornl_first_fifty_years.shtml> [Accessed 3/1/2011]

Krugman, P. "Rare and Foolish," *The New York Times*, p. A35, October 18, 2010

Lancaster, H. (2009) "Putting the right spin on interview answers," Career Journal Europe.com; retrieved from <http://careerjournaleurope.com/jobhunting/interviewing/20011016-careercorner.html>

Languages of India (1995) Library of Congress Country Studies, India, Section 12, retrieved from <http://cweb2.loc.gov/cgi-bin/query/D?cstdy:12:./temp/~frd_i9io::>

Liu, M. & Mazumdar, S., (2007), "Do China and India Produce A Million Engineers?" *Newsweek International*, August 20-27 issue, retrieved from <http://www.msnbc.msn.com/id/20226756/site/newsweek/>

Mankiw, N. Gregory (2009), *Principles of Economics,* (5th Ed.), p. 663. Mason, OH: South-Western Cengage Learning.

Matloff, N. (1998) "Debunking the Myth of a Desperate Software Labor Shortage"Testimony to the U.S. House Judiciary Committee Subcommittee on Immigration. Presented April 21, 1998; updated April 26, 1998. Retrieved from

< http://judiciary.house.gov/legacy/6096.htm> [Accessed 4/03/2011]

McCullagh, D. (2010), Intel CEO: U.S. faces looming tech decline, CNET News, August 24, 2010, retrieved from <http://news.cnet.com/8301-13578_3-20014563-38.html>August 24, 2010 10:59 AM PDT> [Accessed 3/3/2011]

MIano, J. (2010), Making Sure H-1Bs Actually Work for their "Employers", Center For Immigration Studies, retrieved from <http://www.cis.org/miano/h1bjobshops>

Murali, Kanta (2003), "The IIT Story: Issues and Concerns," *Frontline,* 20(3) retrieved from <http://www.flonnet.com/fl2003/stories/20030214007506500.htm> [Accessed 4/1/2011]

North, D. (2011), "Estimating the Size of the H-1B Population in the U.S." Center for Immigration Studies, February, retrieved from <http://www.cis.org/estimating-h1b-population-2-11> [Accessed 4/12/2011]

OECD.StatExtracts (2006 and 2010) Organization for Economic Cooperation and Development (OECD), retrieved from <http://stats.oecd.org/wbos/default.aspx> [First accessed 12/23/2006; latest access 3/3/2011]

OOH (2010) Occupational Outlook Handbook (OOH), 2010-11 Edition, accessible at <http://www.bls.gov/oco/> [Accessed 4/4/2011]

Political Participation (2011) - Race, Ethnicity, And Electoral Districts, retrieved from <http://www.libraryindex.com/pages/2937/Political-Participation-RACE-ETHNICITY-ELECTORAL-DISTRICTS.html> [Accessed 2/23/2011]

Programmers Guild, <http://www.programmersguild.org>, 2009 (latest entries) [Accessed 2/23/2011]

Proposed legislative changes (2005) to H-1B and L-1 visas, retrieved from <http://www.visapro.com/Immigration-News/?a=184&z=48> [Accessed 2/28/2011]

Raghavan, Prabhakar (2007). "India Has The Brains, But Where's The Beef?" www.forbes.com/2007/08/05/india-higher-education-oped-cx_prg_0813education.html

Rai, A. (2010) "IT in India has grown at twice the GDP pace: Steve Mills, IBM", *The Economic Times,* 11/20/2010, accessed from <http://articles.economictimes.indiatimes.com/2010-11-20/news/27582040_1_ibm-steve-mills-software-business> [Accessed 4/4/2011]

Ricardo, D. (1817). *On the Principles of Political Economy and Taxation*. London, Chapter 7, retrieved from

<http://www.econlib.org/library/Ricardo/ricP2a.html#Ch.7,%20On%20Foreign%20Trade> [Accessed 31/2011]

Samuelson, P. A., & Nordhaus, W. (2000). *Economics* (17th Edition), p. 27. Boston,MA: McGraw-Hill

Sanchez, R.(2007), "Immigration Lawyer Indictments Expose H-1B Fraud", VDARE.com 3/24/2007 retrieved from <http://www.vdare.com/sanchez/070324_fraud.htm> [Accessed 4/4/2011]

Schlafly, P. (2003) "What the Global Economy Costs Americans," *The Phyllis Schlafly Report.* Vol. 36, No. 11, Eagle Forum, Alton, IL retrieved from <http://www.eagleforum.org/psr/2003/june03/psrjune03.shtml> [Accessed 2/28/2011]

Situations Responsible for Job Outsourcing to India (2008), retrieved from <http://www.mapsofindia.com/outsourcing-to-india/reasons-for-outsourcing.html> [Accessed 3-31-2011]

TechAmerica (2011). Web site: <http://www.techamerica.org/about-techamerica> [Accessed 4/01/2011]

Teitelbaum, M. S. (2003, Fall). Do we need more scientists? *National Affairs,153 (Fall), 40-53,* retrieved from <http://www.the public interest.com/archives/2003fall/article2.html> [Accessed 2/28/2011]

Tett, G. (2009) *Fool's Gold,* pp. 113-114, New York, NY: Free Press

Thibodeau, P. (2009) "Grassley, Durbin plan to renew H-1B fight in Senate.", *CompuiterWorld,* March 31; retrieved from <http://www.computerworld.com/s/article/9130842/Grassley_Durbin_plan_to_renew_H_1B_fight_in_Senate?taxonomyId=70&pageNumber=2> [Accessed 4/03/2011]

Trade Map (2011) International Trade Statistics, The International Trade Center, retrieved from <http://wwwtrademap.org/tradestat/Service_Selcountry_TS.aspx> [Accessed 3/6/2011]

Turnbull, L. (2009), "Report finds fraud in 20% of H-1B applications," *The Seattle Times*, 2/15/2009 retrieved from <seattletimes.nwsource.com/html/nationworld/2008746255_h1bside15m.html> [Accessed 4/4/2011]

US Census Bureau (2011), "U.S. International Trade in Goods and Services, 1992 – Present," US Census Bureau, Foreign Trade Division retrieved from

<http://www.census.gov/foreign-trade/statistics/historical/index.html> [Accessed 4/5/2011]

US Citiizenship and Immigration Services (2011) Reports and Studies. Characteristics of Specialty Occupation Workers (various fiscal years) retrieved from <http://www.uscis.gov>

US Immigration Lawyer Services (2011) retrieved from <http://www.visapro.com/> [Accessed 2/28/2011]

UT 2008-2009 Graduate and Undergraduate Catalogs.,Knoxville: University of Tennessee

Varma, R. and Varma, D.R. (2009) The Making of Indian Immigrant Entrepreneurs in the US, *Economic and Political Weekly,* January 17,2009

Wasem, R.E. (2004) Immigration: Legislative Issues on Nonimmigrant Professional Specialty (H-1B) Workers, CRS Report for Congress, (Updated February 12, 2004), from <http://trac.syr.edu/immigration/library/P8.pdf > [Accessed 2/28/2011]

Wasem, R.E. (2007) Immigration: Legislative Issues on Nonimmigrant Professional Specialty (H-1B) Workers, CRS Report for Congress, (Updated May 23, 2007), retrieved from migration.ucdavis.edu/wcpsew/files/CRS_5=23=07pdf.pdf [Accessed 2/28/2011]

Appendices

Appendix A --Tables

Table A-1: Number of Post-Secondary Graduates in OECD Nations. Total Number of Graduates, Percent in Computer Science, Other Technical Fields, and in Non Technical Fields, and Sorted by the Percent in Computer Science. (* The Japanese percentage in Computer Science is an estimate based on the values for the combined data.)

	All Graduates	Computer Science %	Other Technical Fields, %	Non-Technical Fields %
All Countries	6,230,006*	4.1	19.2	76.9
Australia	209,115	8.9	12.9	78.2
Mexico	324,013	7.7	17.8	74.6
Ireland	37,069	7	16.3	76.6
New Zealand	38,730	6	12.6	81.5
Iceland	2,600	5.8	11.2	83.1
Norway	30,476	5.7	10.5	83.8
Germany	219,746	4.9	25.9	69.3
Austria	23,071	4.9	22	73.2
Japan *	646,983	4.7	17.3	75
Portugal	4,649	4.5	30.2	65.3
Finland	38,819	4.4	25.4	70
Greece	35,779	4.4	23.2	72.3
Slovak Republic	32,537	4	22	73.9
United States	**2,089,901**	**3.9**	**12.2**	**84**
Spain	210,603	3.9	21	75.1
Netherlands	96,980	3.7	12.5	83.9
Canada	177,433	3.6	15.8	80.6
Switzerland	28,549	3.4	21.8	74.9
Korea	303,559	3.3	35.3	61.4
Sweden	54,504	3.2	25.5	71.4
Denmark	39,236	3.2	15.2	81.6
France	412,346	3	25.5	71.5
Czech Republic	46,097	2.8	21.7	75.5
Poland	479,458	2.7	9.5	87.8
Belgium	38,304	2.7	20.4	76.9

Hungary	72,652	1.9	7.7	90.4
Italy	321,284	1.2	21.8	77.
Turkey	215,603	1	16.4	82.7

Table. A-2 Table of graduates in OECD nations in 2004 sorted by number of graduates in computer science. Some minor inconsistencies due to round-off error exists. (*Specific field numbers for Japan are estimates. Only the total number of graduates for Japan reported.)

OECD Country	Number of Graduates	Computer Science	Other Technology	Non-Technical Fields
All Countries	6,230,006	211,820	1,102,711	4,915,475
United States	2,089,901	81,506	254,968	1,755,517
United States % of Total	**34%**	**38%**	**23%**	**36%**
Japan*	646,983	25,879	135,866	485,237
Mexico	324,013	24,949	57,674	241,714
Australia	209,115	18,611	26,976	163,528
Poland	479,458	12,945	45,549	420,964
France	412,346	12,370	105,148	294,827
Germany	219,746	10,768	56,914	152,284
Korea	303,559	10,017	107,156	186,385
Spain	210,603	8,214	44,227	158,163
Canada	177,433	6,388	28,034	143,011
Italy	321,284	3,855	70,040	247,710
Netherlands	96,890	3,585	12,111	81,291
Ireland	37,069	2,595	6,042	28,395
New Zealand	38,730	2,324	4,880	31,565
Turkey	215,603	2,156	35,359	178,304
Sweden	54,504	1,744	13,899	38,916
Norway	30,476	1,737	3,200	25,539
Finland	38,819	1,708	9,860	27,173
Greece	35,779	1,574	8,301	25,868
Hungary	72,652	1,380	5,594	65,677
Slovak Republic	32,537	1,301	7,158	24,045
Czech Republic	46,097	1,291	10,003	34,803
Denmark	39,236	1,256	5,964	32,017
Austria	23,071	1,130	5,076	16,888
Belgium	38,304	1,034	7,814	29,456
Switzerland	28,549	971	6,224	21,383
Portugal	4,649	209	1,404	3,036
Iceland	2,600	151	291	2,161

Table A-3. BLS Wage Data (May 2008) for Various Computer Occupations Compared to All Occupation

Job Designation	SOC Number	Employment	Annual Mean Wage	Median Wage	75%	90%
All Occupations	00-0000	135,185,230	$42,270	$32,390	$51,540	$79,020
All Computer Workers and Mathematicians.	15-0000	3,308,260	$74,500	$71,270	$94,230	$117,900
Computer Scientists	15-1011	26,610	$100,900	$97,970	$124,370	$151,250
Programmers	15-1021	394,240	$73,470	$69,620	$89,720	$111,450
Computer Hardware Engineers	17-2061	73,370	$100,190	$97,400	$122,700	$148,590

Table A-4: Nominal Annual Wages for Computer Occupations (2009)

Occupation Code	Occupation Title	Number Employed	Median Hourly	Mean Hourly	Mean Annual	Median Annual
15-0000	Computer and Mathematical Science Occupations	3,303,690	$35.05	$36.68	$76,290	$72,904
15-1011	Computer and Information Scientists, Research	26,130	$48.83	$50.66	$105,370	$101,566
15-1021	Computer Programmers	367,880	$34.10	$35.91	$74,690	$70,928
15-1031	Computer Software Engineers, Applications	495,500	$42.06	$43.35	$90,170	$87,485
15-1032	Computer Software Engineers, Systems Software	385,200	$44.94	$46.45	$96,620	$93,475
15-1041	Computer Support Specialists	540,560	$21.30	$22.77	$47,360	$44,304
15-1051	Computer Systems Analysts	512,720	$37.06	$38.67	$80,430	$77,085
15-1061	Database Administrators	108,080	$34.40	$35.72	$74,290	$71,552
15-1071	Network and Computer Systems Administrators	338,890	$32.55	$34.10	$70,930	$67,704
15-1081	Network Systems and Data Communications Analysts	226,080	$35.22	$36.81	$76,560	$73,258
15-1099	Computer Specialists, All Other	195,890	$37.02	$37.50	$78,010	$77,002
17-2061	Computer Hardware Engineers	65,410	$47.51	$48.75	$101,410	$98,821
00-0000	**All Occupations**	130,647,610	$15.95	$20.90	$43,460	$33,176

Table A-5 : Change in Real Median Wage for Various Professions During the Period 1999-2008

Profession	Standard Occupation Code	Real Wage, 1999	Real Wage, 2008	Annual %Change
	1999 CPI = 166.6	2008 CPI =215.303	1982 CPI = 100	
All Occupations	00-0000	$15,280	$15,042	-0.2
Financial systems Analysts	13-2051	$29,531	$33,975	1.6
All Computer Occupations	15-0000	$31,200	$33,098	0.7
Computer Scientists	15-1011	$39,178	$45,502	1.9
Computer Programmers	15-1021	$30,651	$32,335	0.5
Computer Hardware Engineers	17-2061	$38,854	$45,239	1.5
Physicists	19-2012	$45,702	$49,437	0.9
Registered Nurses	29-1111	$25,378	$29,006	1.5
Fabric Patternmakers	51-6092	$13,265	$17,538	3.0

Appendix B – Figures
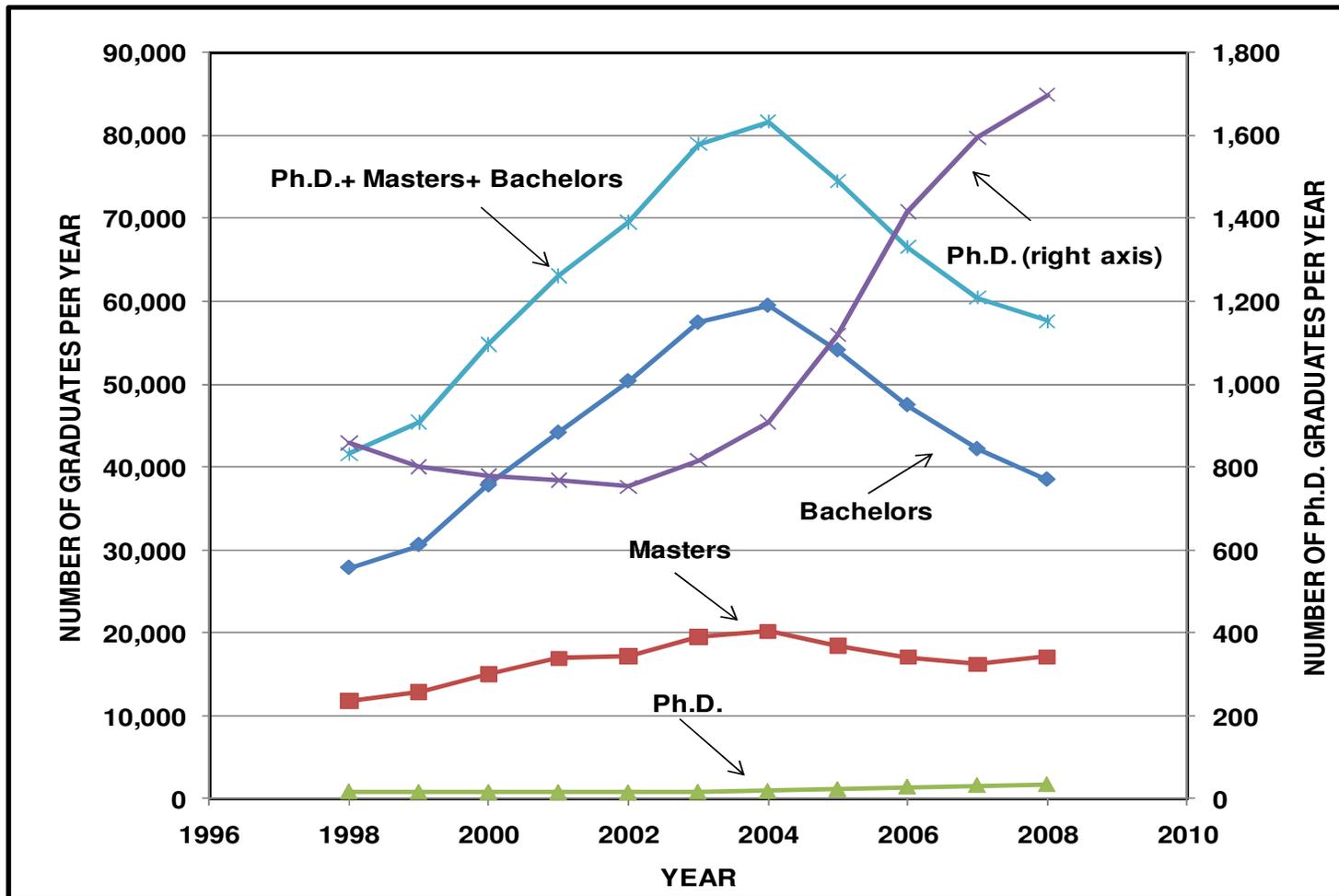
Fig. B-1 Annual number of degrees granted in the United States in computer science for the period 1998-2008.
The data for Ph.D. degrees is plotted in two ways to show its own behavior and also relative to the other curve
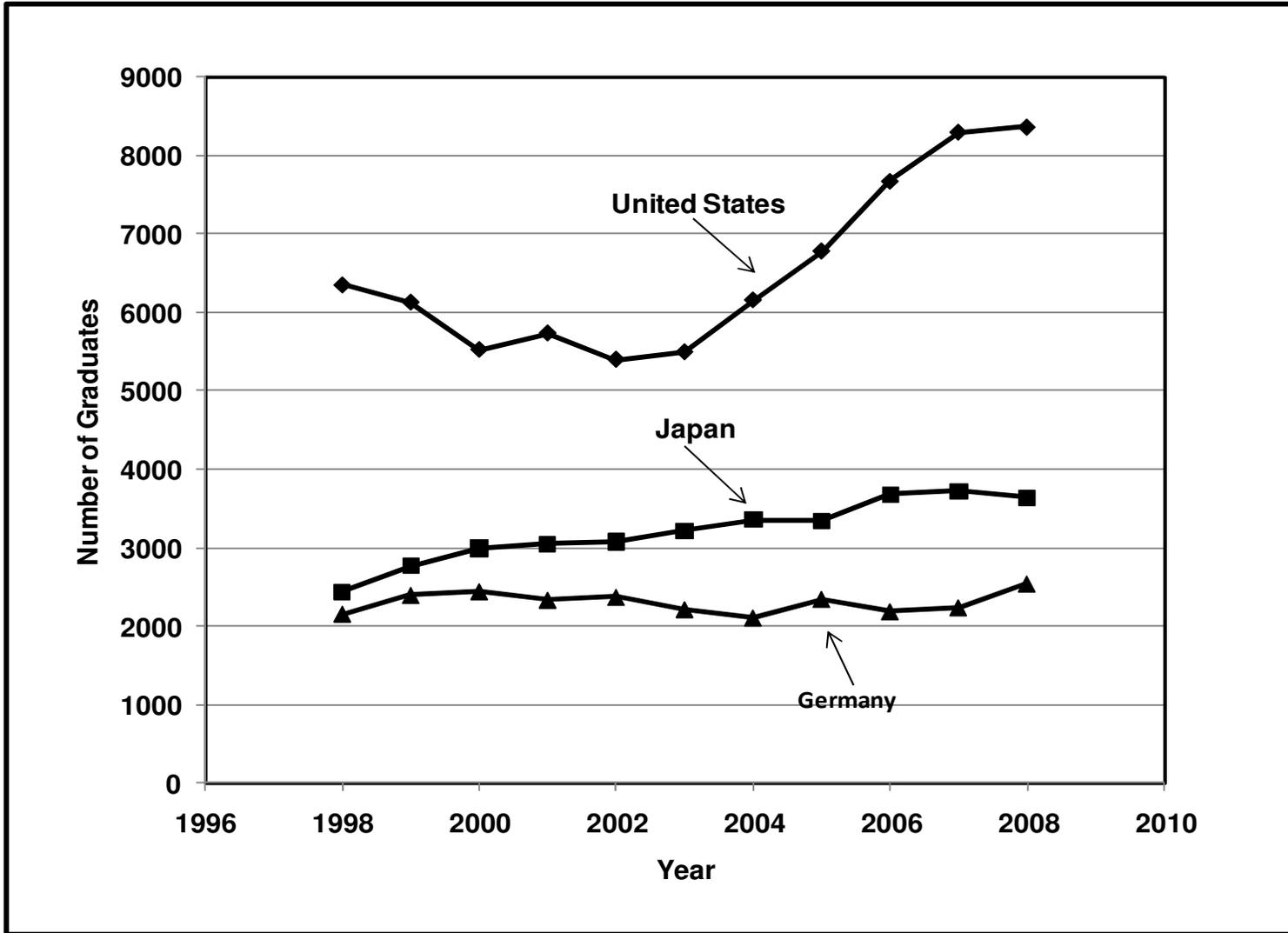
Fig. B-2: Number of graduates in engineering produced by the United States, Japan and Germany, 1998-2008.
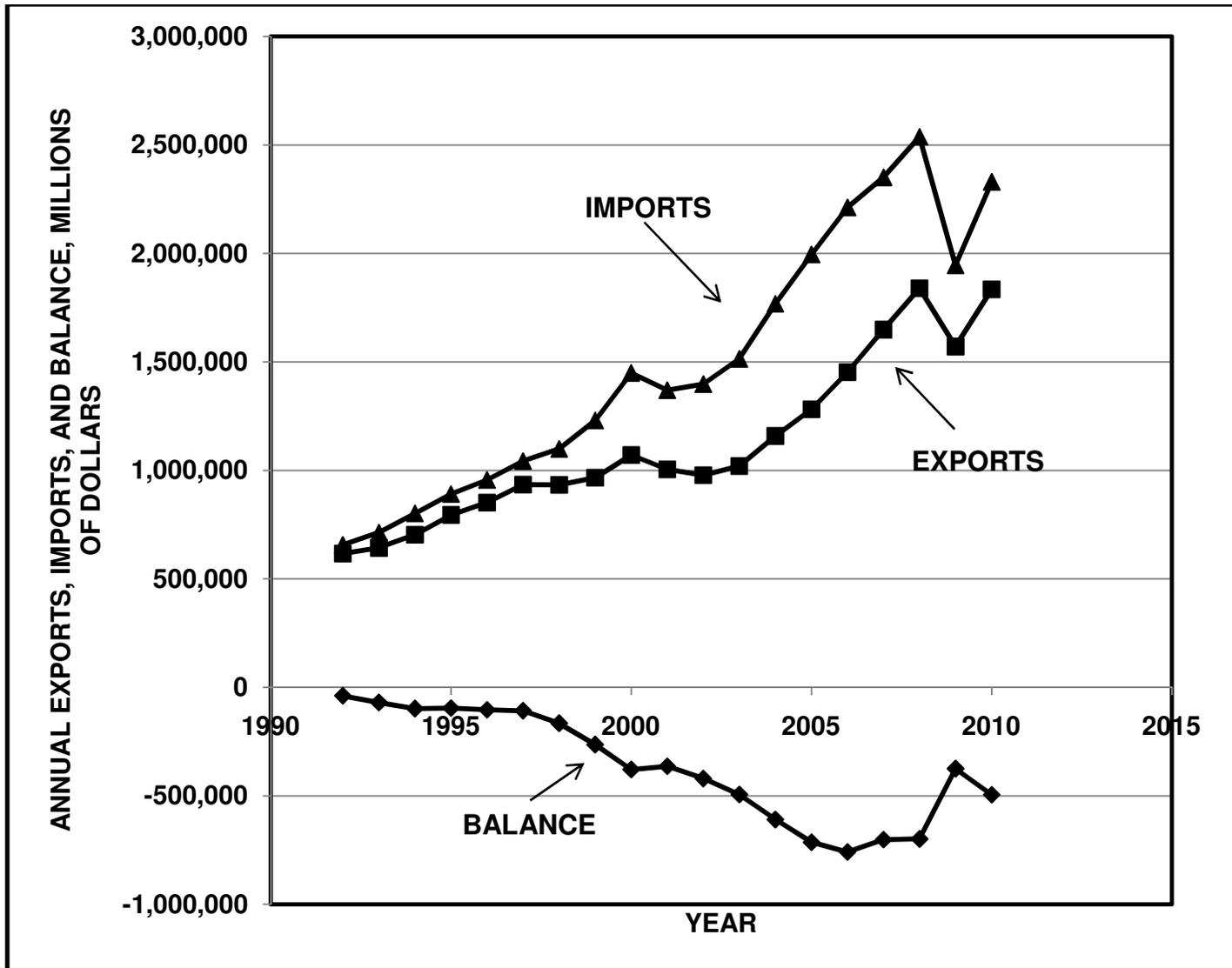
Fig. B-3: United States Import/Export values (BOP basis) and balance values, 1992-2010. (The top value on the vertical axis is 3 trillion dollars
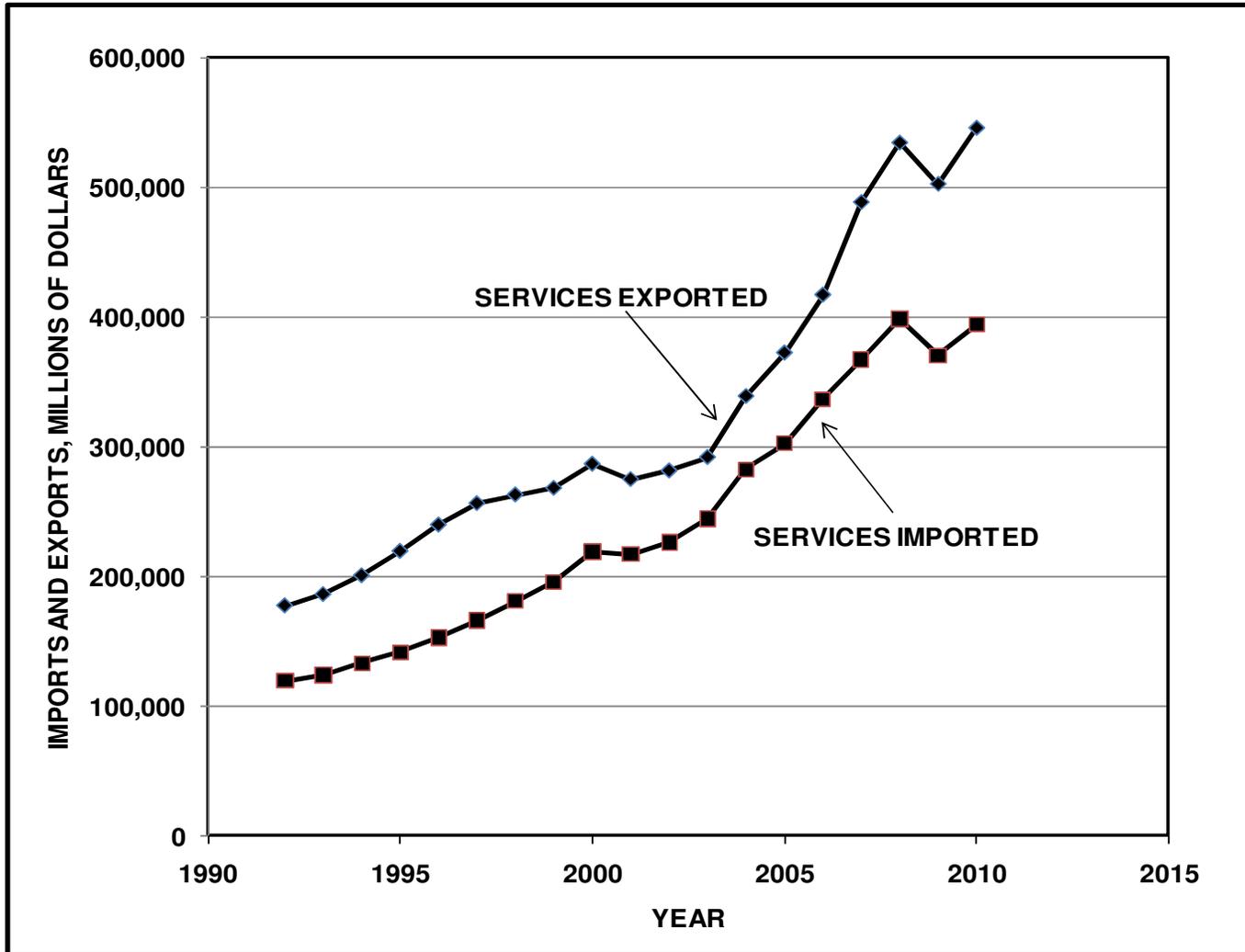
81

Fig. B-4: Values of United States trade in services, 1992-2010 showing positive balance of trade.
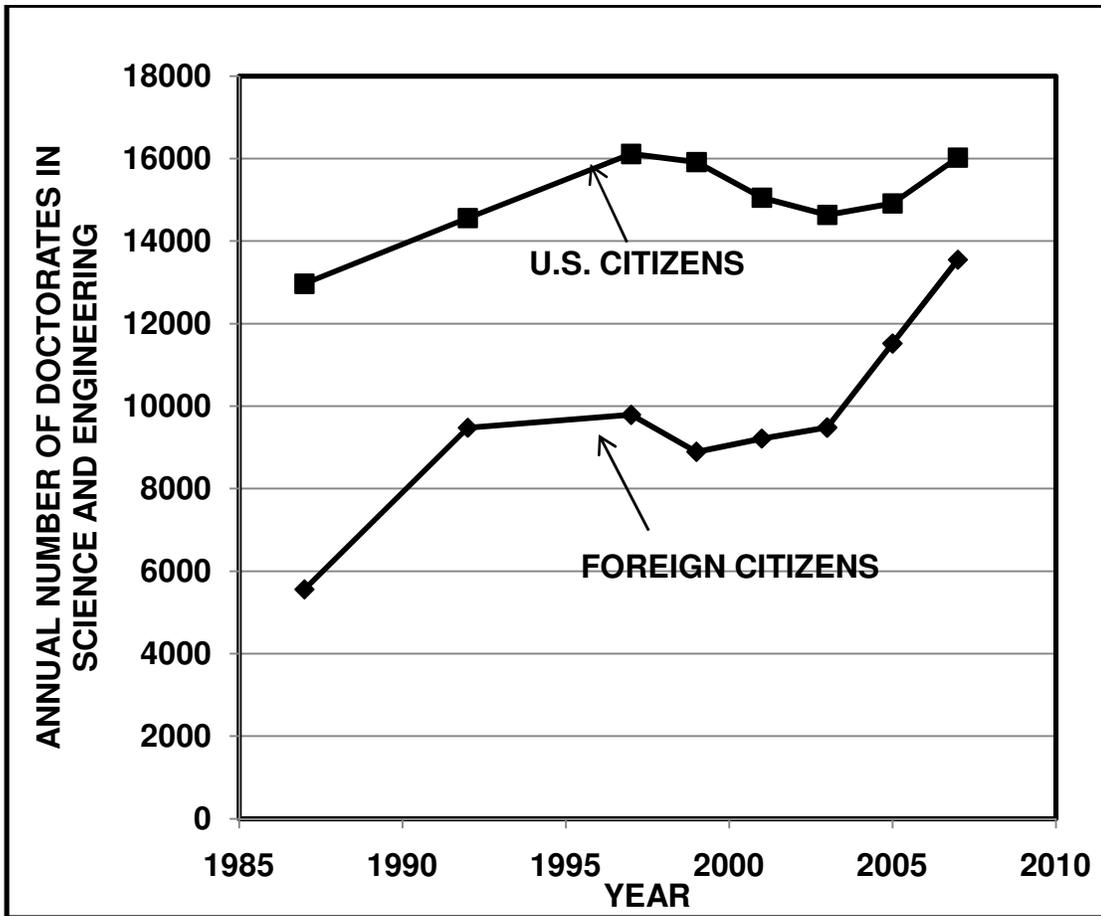
Fig. B-5.: Number of doctorates in science and engineering awarded in the United States to U.S. and foreign citizens 1987-2007
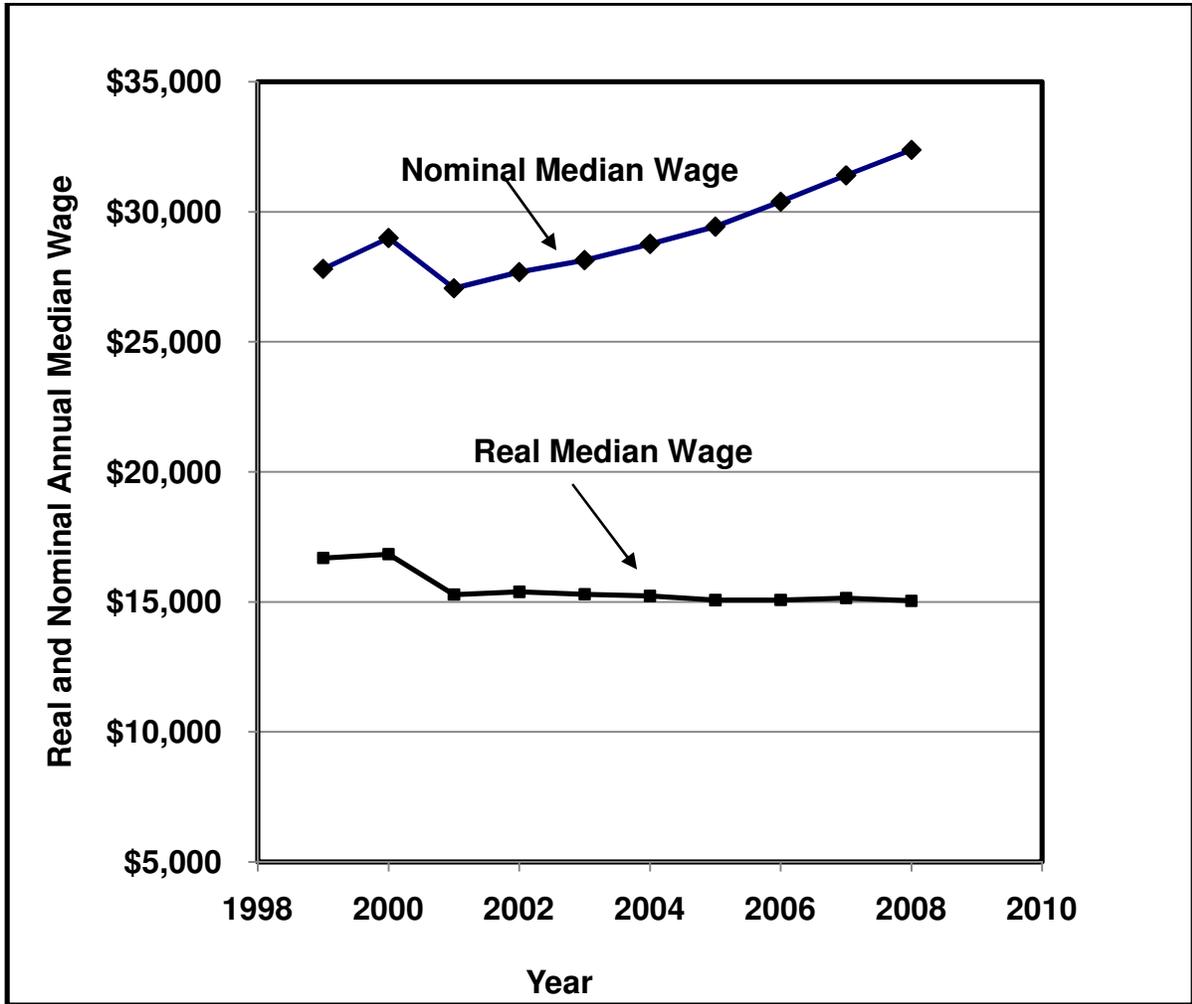
Fig. B-6: Real and nominal annual wage for all workers (i.e., the "average" worker), 1999-2008
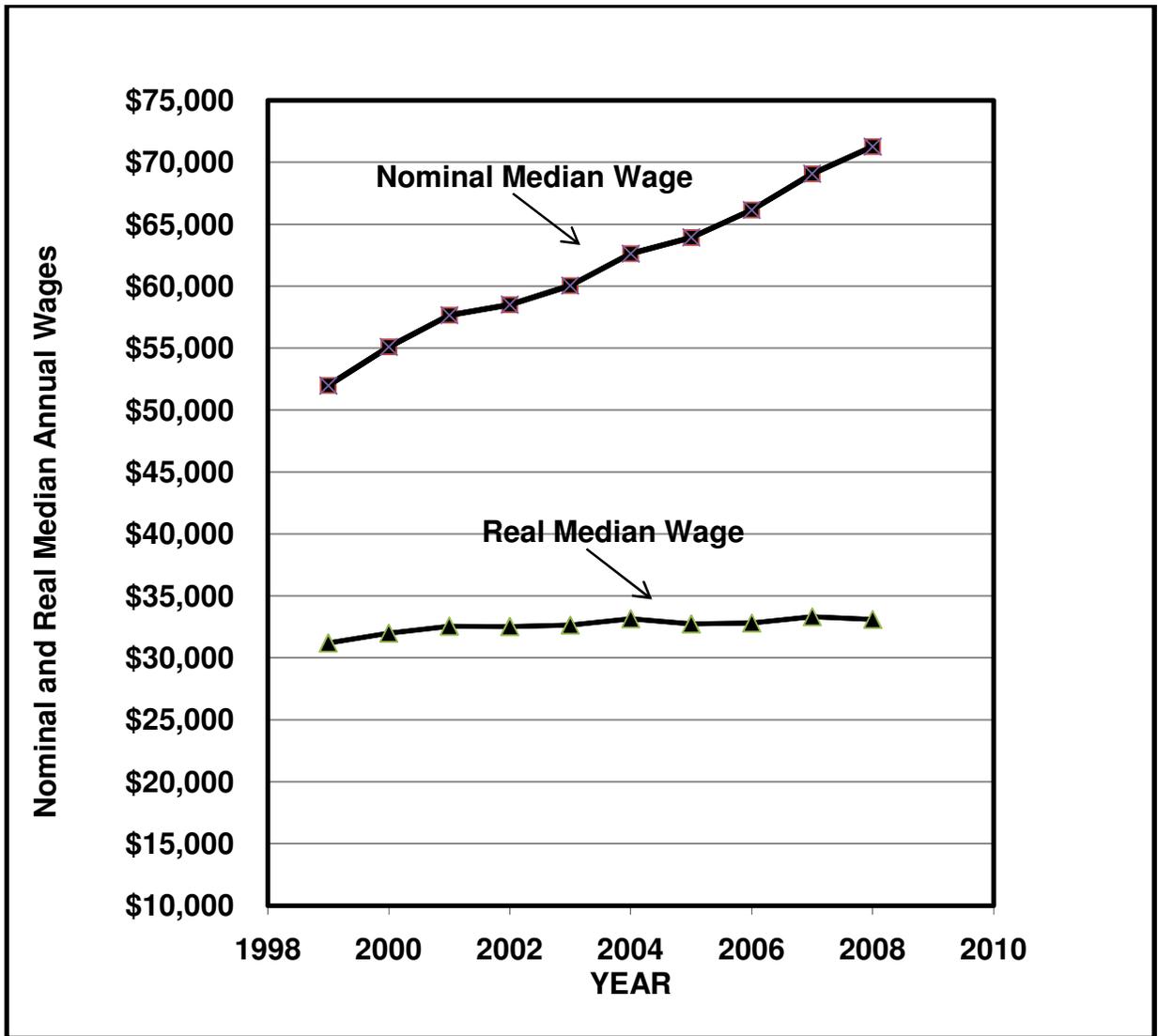
Fig. B-7: Nominal and real median annual wage for all computer occupations. (SOC 15-0000)
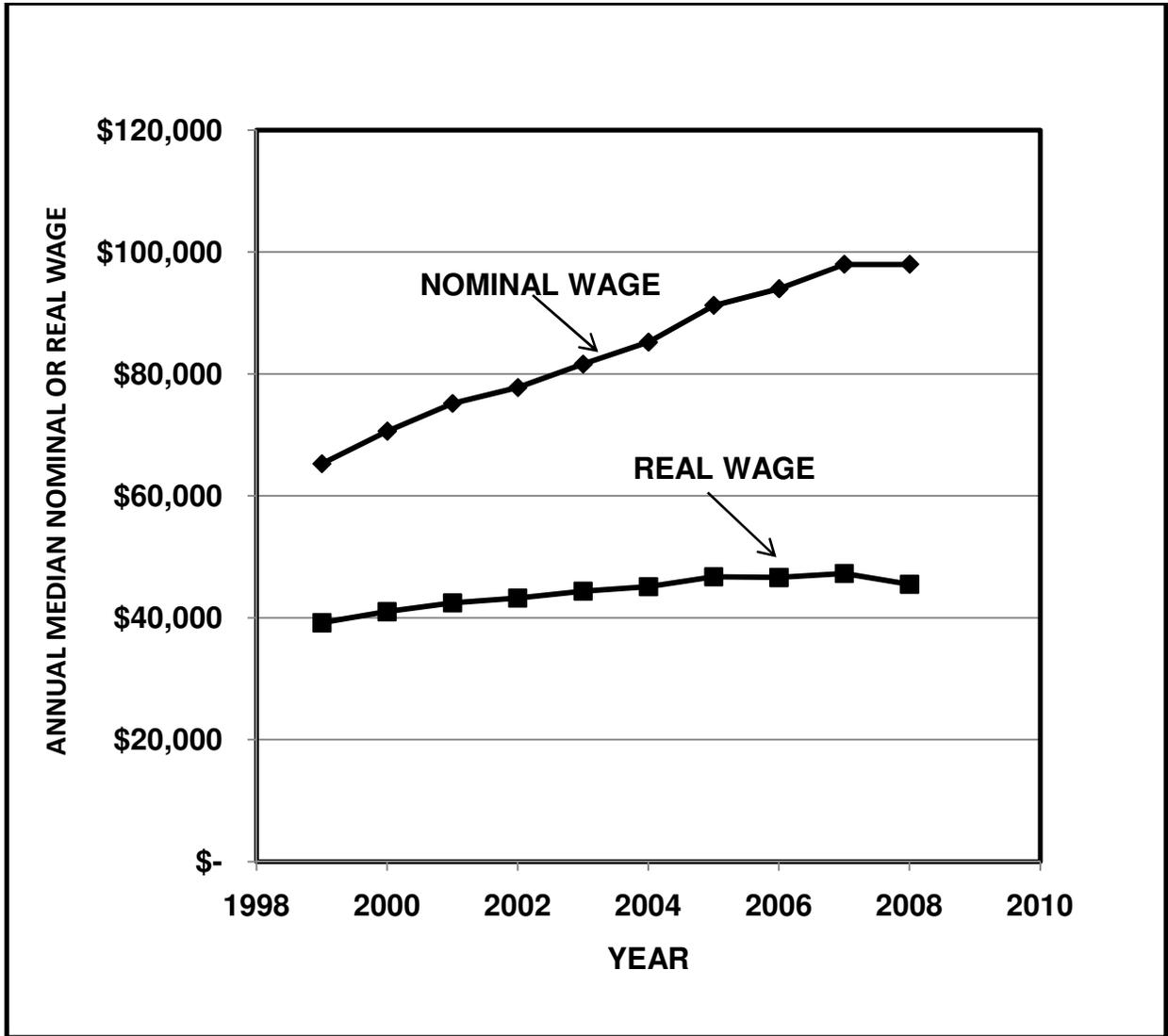
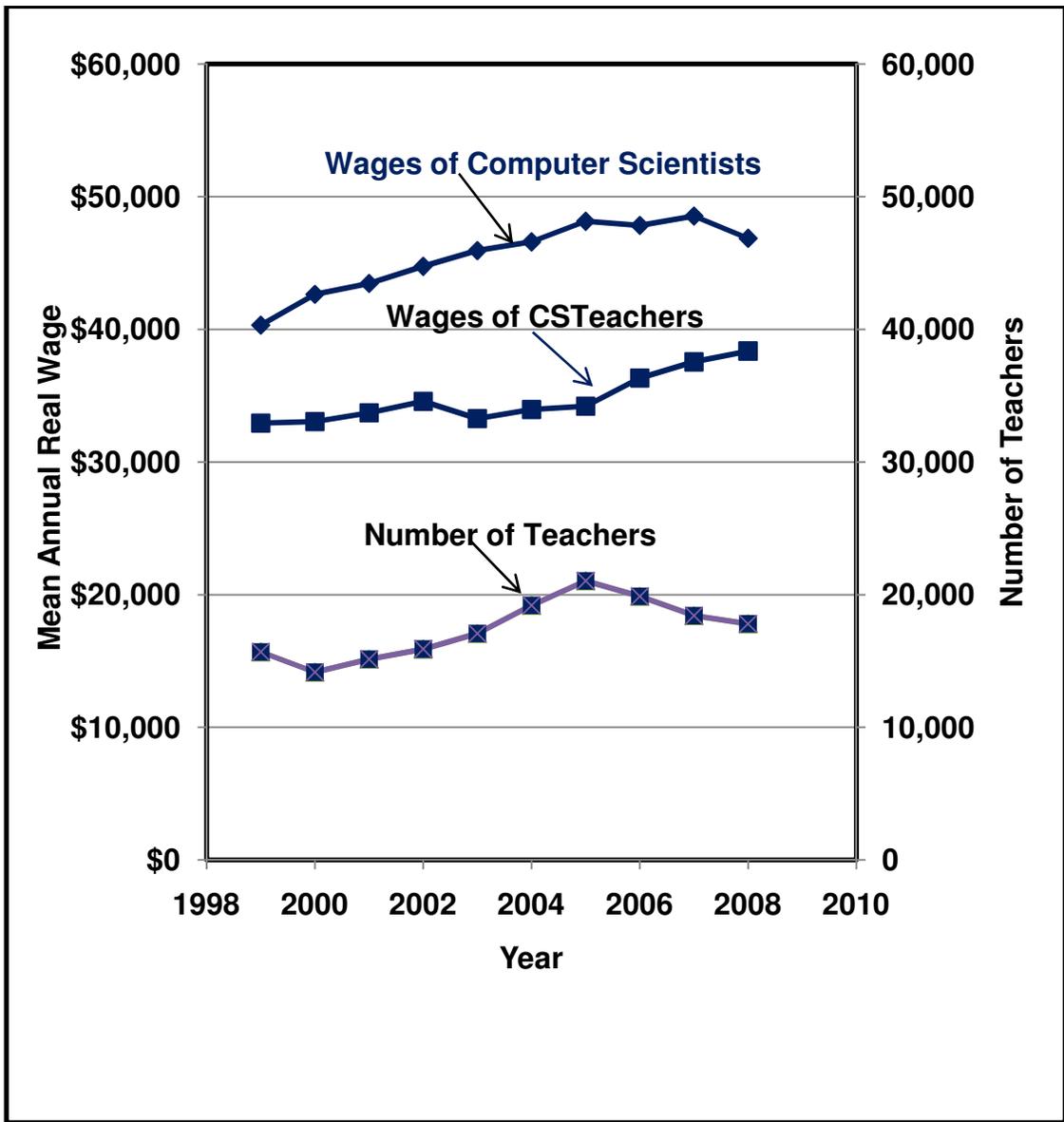Fig.B-8: Real and nominal annual median wage for computer scientists, SOC-1011

Fig. B-9: Real and nominal median annual wage for compute science teachers (SOC 25-1021) and their number, compared to wages of computer scientists.
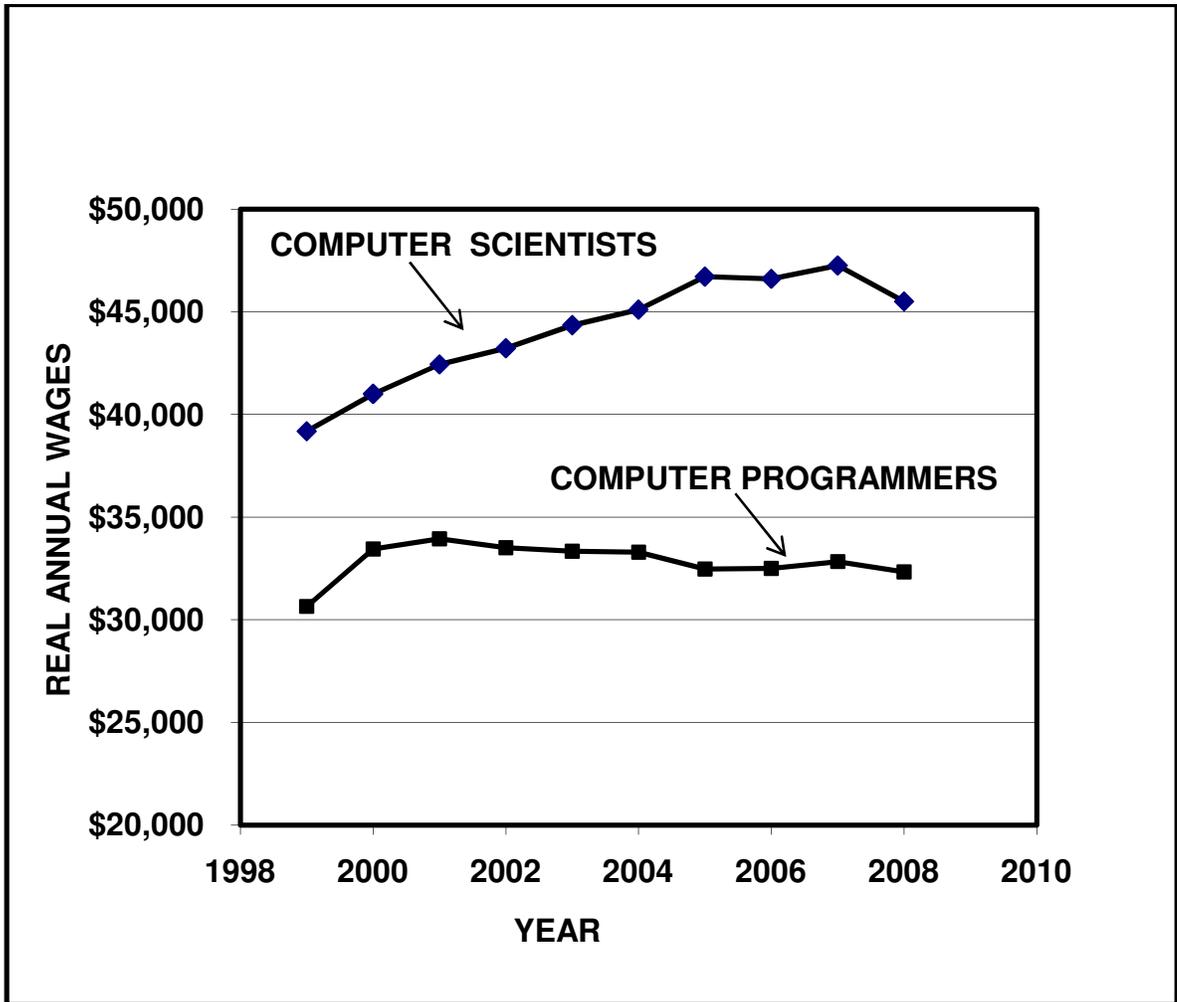
Fig. B-10: Real annual median wages for computer programmers (SOC-1021) compared to those for computer scientists (SOC 10-1011)
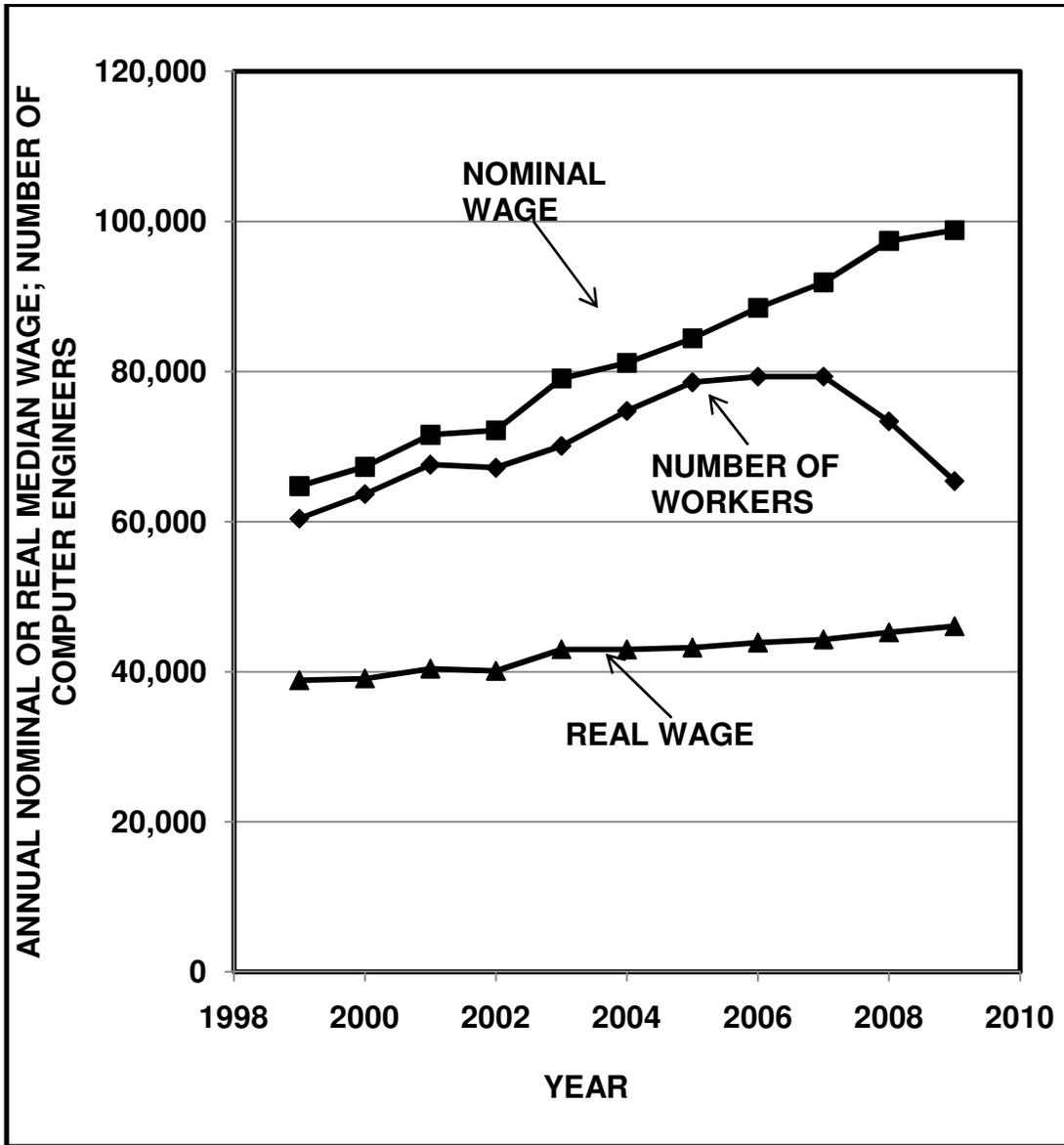
Fig. B-11: Annual nominal median wage, real wage, and number of computer hardware engineers (SOC 17-2061) employed.
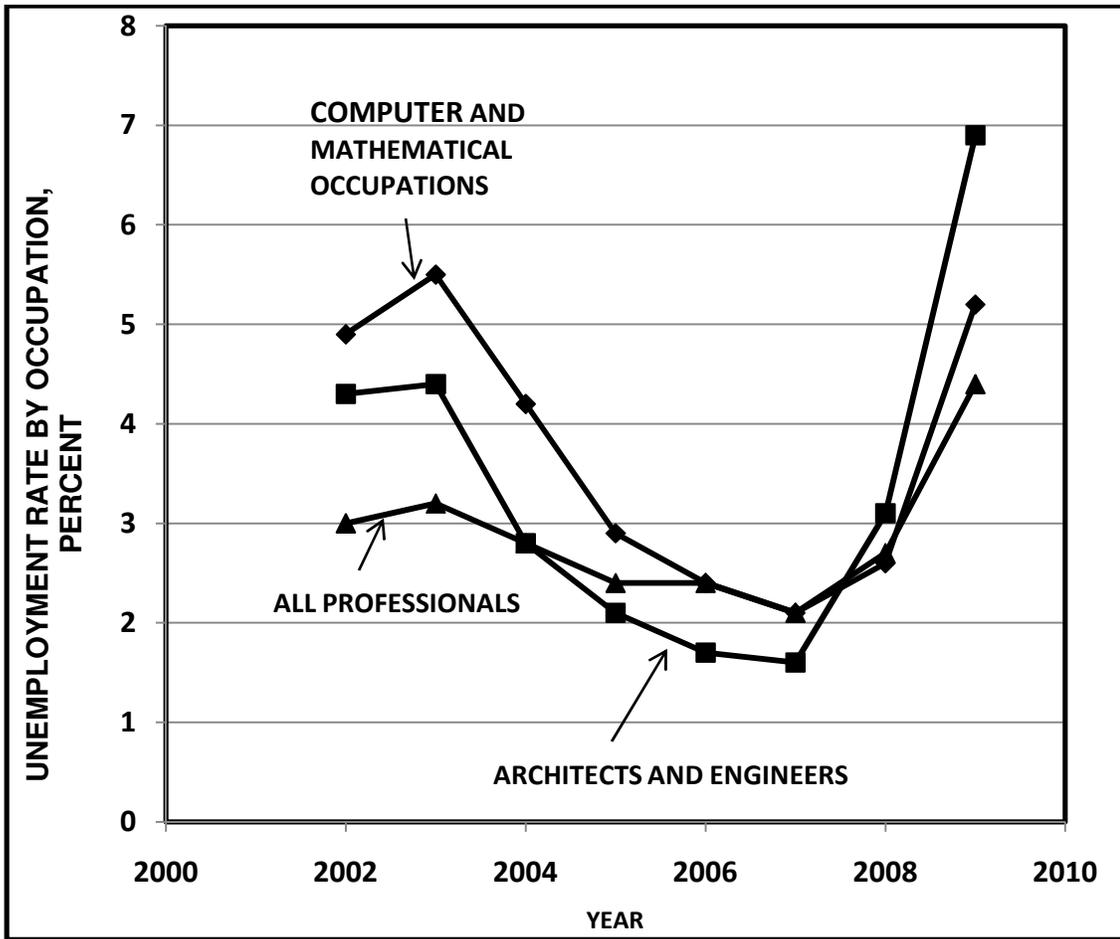
Fig. B-12: Unemployment rates for computer workers, architects and engineers and professional workers collectively, 2002-2009.
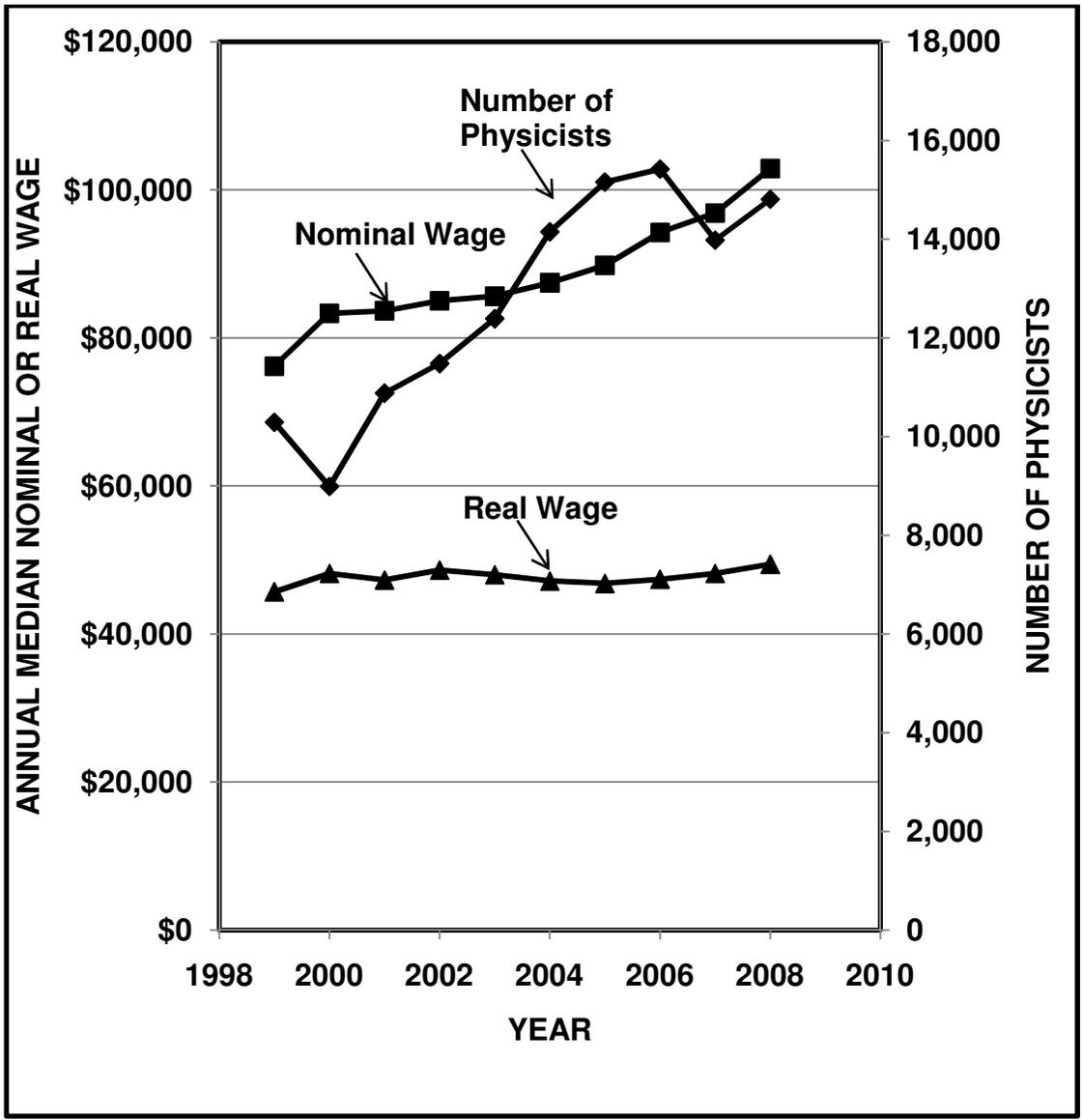
Fig. B-13: Annual median nominal and real wages, and number of physicists, SOC 19-2012, 1999-2008
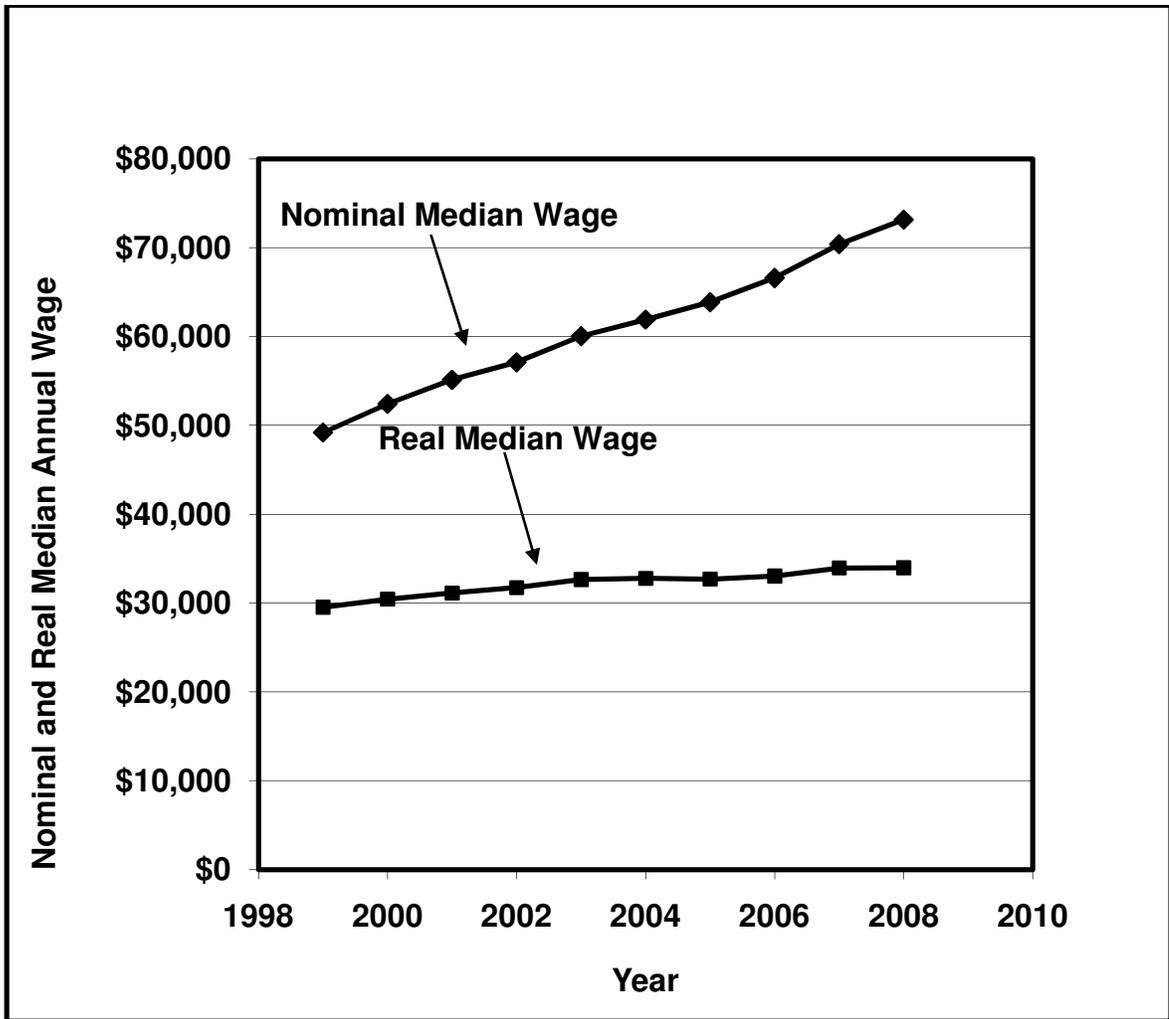
Fig. B-14: Nominal and real annual median wages for financial systems
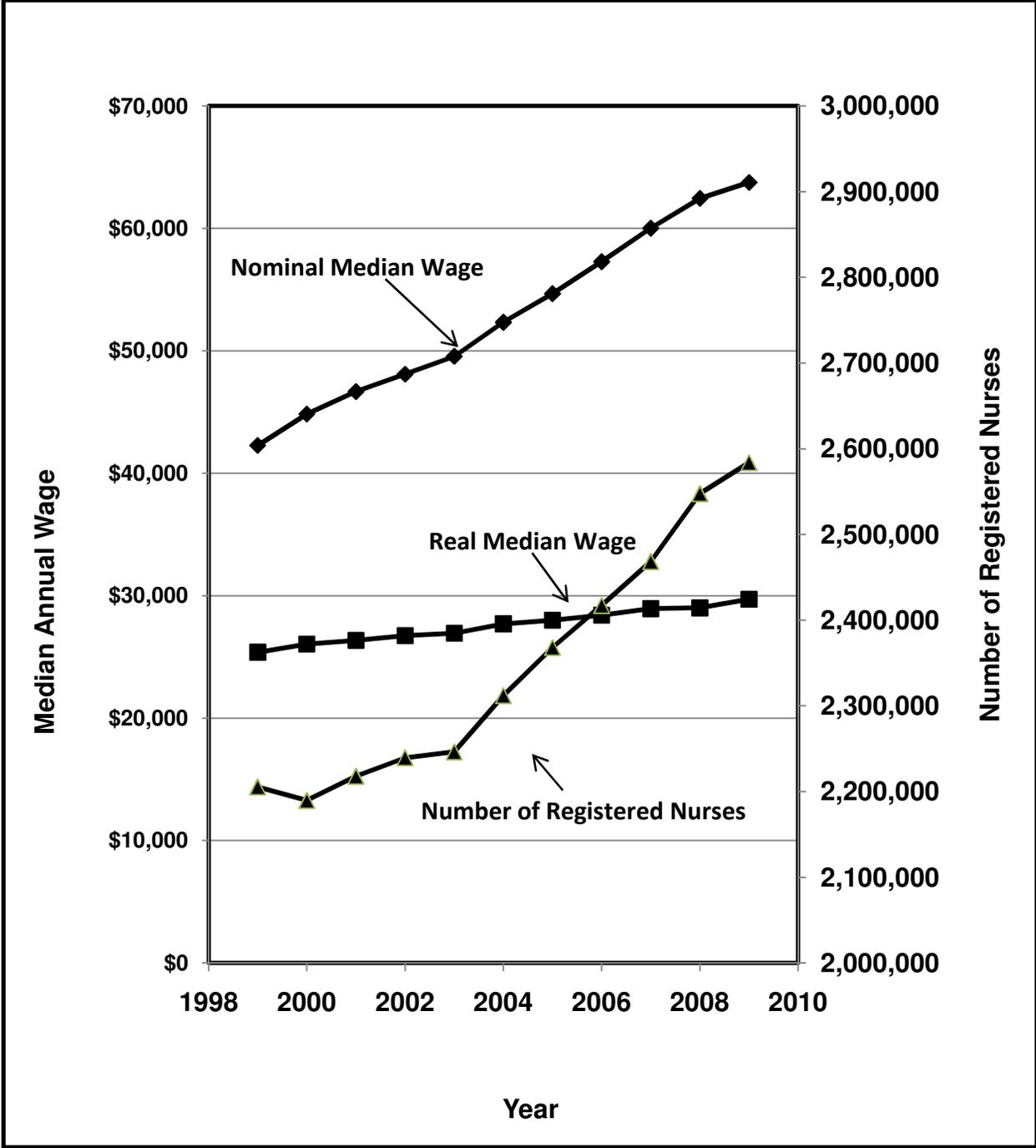analysts, SOC 13-2051, 1999-2008

Fig. B-15: Nominal and Real Median Wages for Registered Nurses; Number of
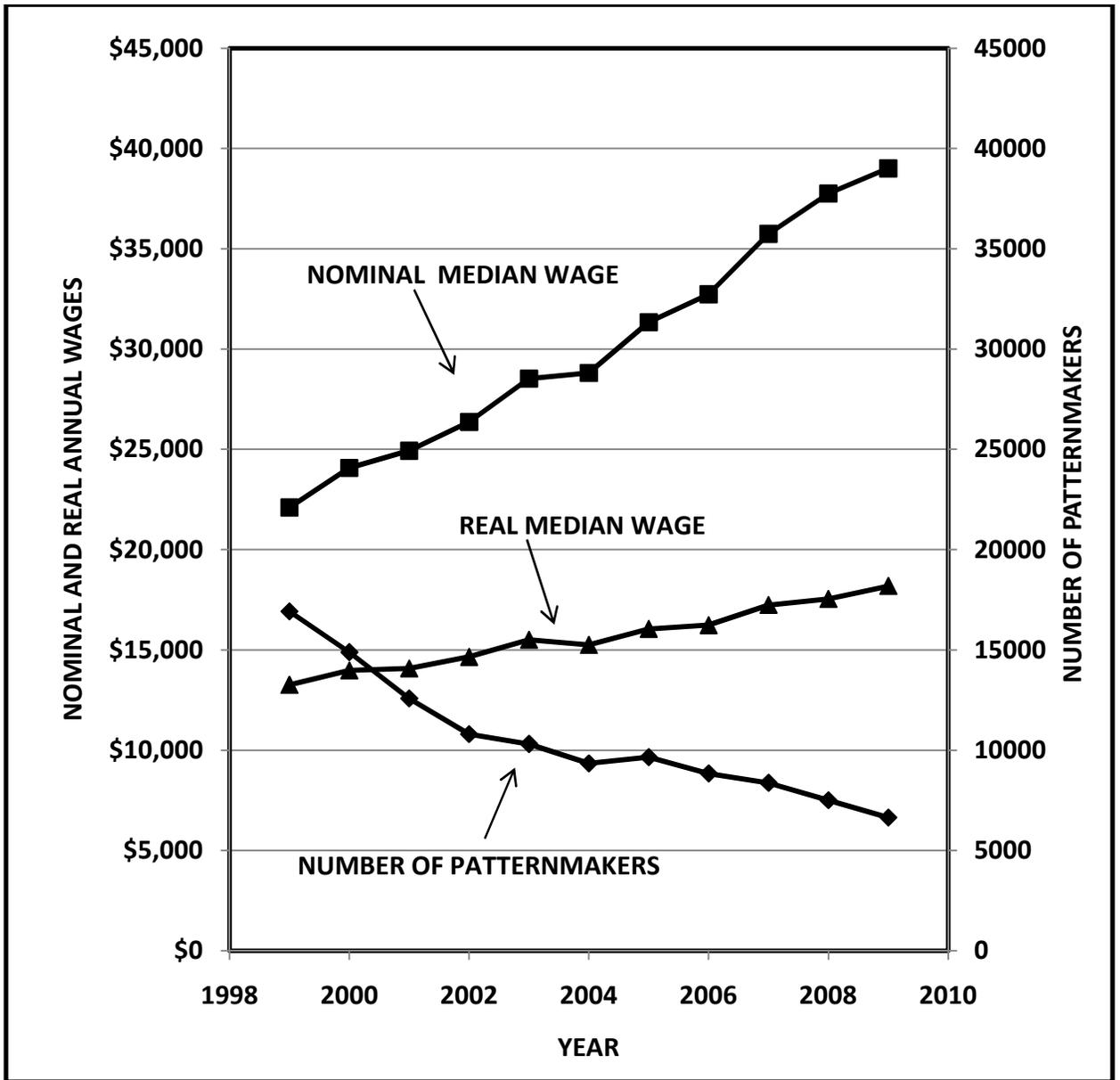Registered Nurses, SOC 29-1111.

Fig B-16: Nominal and Real Annual Wages and Number of Patternmakers, 1999-2009

Appendix C

University of Tennessee Curricula in Computer Science and Computer Engineering

The Bachelor's Degree Programs in Computer Science and Computer Engineering at the University of Tennessee

The bachelor's degree outcomes are based on the ABET (Accreditation Board for Engineering and Technology) Engineering Criteria 2000. The student must complete 30 hours of upper-division courses in the department and a grade of at least C is required in all these courses. The student can major in either computer engineering or computer science. The four-year curricula are as follows:

C.1. Computer Engineering
The first two years are devoted to studies of fundamental applied mathematics (differential and integral calculus, differential equations, matrix algebra, and probability theory), physics (emphasizing electricity and magnetism) and general chemistry. Out of the total of 64 credit hours in these subjects, 25 credit hours among them are intended to meet the University General Education Requirements. The student is introduced to the use of computers in electrical engineering calculations and basic ideas of digital systems. English Composition is included for training in skills of written technical communication.

First Year: English Composition, General Chemistry, Differential and Integral Calculus, Physics for Engineers (calculus based), Computer Methods in Engineering Problem Solving, Electrical Engineering Computations (computer methods)

Fundamentals of Electricity and Magnetism, Wave Motion, Optics, and Modern Physics, Logic Design of Digital Systems, Probability Theory, Electric Circuit Theory, Advanced Problem Solving Techniques Involving Data Structures

The succeeding two years intensify studies of the design of computers. Additionally, in the fourth year, the student is required to take 18 credit hours out of the total Bachelor's degree total of 128 in electives in philosophy, social sciences, arts and humanities &c. to conform to University General Education Requirements. There is also a review course of topics covered in the morning session of the Fundamentals of Engineering examination, which is an important step in eventual licensure. The technical courses are listed below.

Third Year:

Electrical and Computer Engineering 315, 316 -- Mathematical analysis of continuous and discrete-time functions to model signals, using such tools as Fourier series, Laplace transforms, z-transforms, sampling theory, etc.

Electrical and Computer Engineering 335 -- The physics of semiconductors and the theory of p-n junctions, transistors, and transistor devices; the analysis and design of switching, amplifying, and rectifier circuits, etc. Laboratory work is included for design projects.

Electrical and Computer Engineering 342 – The study of frequency and amplitude modulation in analog communication involving probability and random variables, signal-to-noise ratio, etc. Laboratory experimental work is included.

Electrical and Computer Engineering 355, 395 – Introduction to computer system fundamentals such as machine-level computer organization and programming, microprocessor and memory architectures, structured assembly language programming, computer communication, &c. and computer security problems. Design problems are included which require laboratory work. Course 395 is a junior seminar in which the students engage in presentations and discussions of topics in professional development, ethics, and current technical topics.

Computer Science 302 – Design and analysis of fundamental algorithms, e.g. sorting and searching and the associated data structures.

Computer Science 360 – Systems programming involving file control, process control, memory management, system utilities, and networks

Mathematics 300 or honors version – Introduction to abstract mathematics: algebra of sets, the real number system and like topics.

Fourth Year:

Electrical and Computer Engineering 451, 453 or 451, 455 (All of these courses include laboratory work on projects.)

451: Architecture and design of microcomputer systems with microprocessors or microcontrollers. Instruction set architectures, software interfaces, processor structures, memory hierarchy, and interfacing.

453: Principles of computer networking and software design of network protocol with emphasis on the Internet.

455: Design and development of embedded systems for data acquisition and special-purpose computer systems, e.g., peripheral interfacing, serial/parallel communications, etc. Assembly language programming, software architecture and machine architecture of microcontrollers.

Electrical and Computer Engineering 400 – a major design project that is to include everything the student has learned and also recent developments in the field.

Computer Engineering Senior Electives (6 credit hours) Courses above the 400 level in electrical and computer engineering.

C.2: Computer Science Major

As in the curriculum for Computer Engineering majors, the first two years are devoted to studies of fundamental applied mathematics (differential and integral calculus, differential equations, matrix algebra, and probability theory), physics, and general chemistry.   There is the same allotment of 25 credit hours to meet the University General Education Requirements.   There are a number of minor alternative course differences but the general academic pattern for the first two years is much the same as that shown above for the Computing Engineering major. The most significant difference is the stronger emphasis in the latter on electricity and magnetism, whereas the Computer Science Physics 135-136 sequence covers thermodynamics and mechanics more. It is in the last two years that the strongest differences appear. (The various non-technical elective requirements have been omitted from this listing. They are similar to those cited above for Computer Engineering.)

Third Year:

Computer Science 360 – Systems programming, file and process control, memory management, system utilities and network programming.

Computer Science 365 – Programming languages, language design and logic

Computer Science 380 – The theory of computation, introducing the student to advanced, highly abstract computing concepts, such as countability, diagonalization, finite automata and regular sets. Push-down automata, context-free languages, Turing machines, and undecidability.

Computer Science 340 or 370 or Math 371:

340: Principles and design of information systems, program design and verification.

370: The design of programs, methods, and numerical algorithms for solving problems engineering and science problems, including data structures, computational complexity, and high performance software packages.

Math 371: Development of numerical algorithms for finding roots of equations, solutions to systems of linear equations, least squares data fitting, carrying out differentiation and integration, and obtaining solutions to differential equations.

Mathematics 323 or Electrical & Computer Engineering 313

Math. 323: Probability and statistics.

Electrical and Computer Engineering 313: Probability and random variables.

Fourth Year:

Computer Science 400: This is the analog of the 400 course in Computer Engineering, a senior design project embodying all the student has learned and with attention to recent developments.

Computer Science Upper Division Electives (> 400; typically 494) Course 494 is "Special topics in Computer Science" and can be repeated for a maximum of 18 credit hours.

The above outlines of the Bachelor's degree programs in Computer Science and Computer Engineering clearly describe a thorough and demanding set of courses. A feature of the curricula, somewhat implied in the descriptions of the 400 courses, is the emphasis on the student being made aware of the importance of keeping up with the numerous changes in these rapidly evolving fields. Thus, while the student will certainly make use of programming in specific languages, the university courses go well beyond developing such skills.

The Master's and Doctoral Programs in Computer Science and Computer Engineering

The Master's degree computer engineering student may choose between three options: a thesis option, an non-thesis course-only option, and a non-thesis project option. All of these options require a total of 30 hours with at least 6 credit hours selected from the following 7 Electrical and Computer Engineering courses 551-557:

551 and 552: Digital System Design I and II

553: Computer Networks

554: Computer Security and Forensics

555: Embedded Systems. – Examples of these are sensor and activator networks, multimedia devices and avionics and the several topics associated with them.

556: Wireless Sensor Networks

557: Computer Architecture and Design – Considers the central issues of instruction set design, addressing and register set design, control unit design, microprogramming, etc.

Additional advanced level courses are required. The number of credit hours to be taken depends upon which of the three Master's degree option has been chosen. The thesis option requires a final oral exam. In the non-thesis course-only option, there will be a final comprehensive written examination. There are final written and oral examinations for the non-thesis project option.

The Master's program for Computer Science has a similar structure of 3 options, all of which require the courses Computer Science courses 530, 560, and either 580 or 581. These are as follows:

530: Computer Systems and Organization – Architectures and systems organization for serial and parallel machines.

560: Software Systems – Design of compilers and contemporary software systems; optimization; run-time storage administration.

580: Foundations of computer science, including Turing machines, computability, and computational complexity.

581: Algorithms – Design of efficient algorithms; sorting, searching, graph algorithms, pattern matching, dynamic programming, efficient approximation algorithms.

As with the Master's requirements for Computer Engineering, other course requirements are made which vary with the option chosen.

The doctoral programs of both Computer Engineering and Computer Science need not be detailed here. The usual requirements for advanced (600 level) courses and comprehensive written and oral examinations are made, as well as that for a dissertation based on original research.   As in the undergraduate programs, there is much emphasis on current research and new developments in the field.

Appendix D. Reports of Post-Graduate Experience by University of Tennessee Computer Science Graduates.

There were 22 reports in all, 6 from BSs, 9 from MSs, and 7 from PhDs. We have listed 16 that we consider the more interesting of the reports. Each of the short summaries here is preceded by the graduation date of the alumnus. Note that none of the alumni dates are more recent than 2004.

Bachelor's Degree Graduates

[2004] Worked at Sandia National Laboratory (a government sponsored institution active in defense and security programs) for 3 years on web based applications and on a business project management (BPM) system. Now at Stanford University pursuing a master's degree in computer science.

[1996] Employed at FedEx. Designs and writes software. Most often concerned with applications in JAVA 2 Platform Extended Enterprise (J2EE). Credits the UT computer sciences courses as contributing to his success.

[2004] Project Manager for GE – Consumer Finance. Works internationally on business-related problems

.

[2001] Senior Application Developer at DPRA, Inc. (a consulting firm) Designed a satellite mapping/GPS/auto-routing system for military application. Working on Microsoft Certification (MCSD) relating to business software.

[2002] Employed by National Instruments, a company that develops software and hardware for test and measurement applications.

[2003] Research specialist at UTK in Biochemistry. Developing a software system for performing structure calculations for protein complexes

Master's Degree Graduates

1. [2003] Research Associate at the Computational Biology Institute at Oak Ridge National Laboratory using C++ programming and providing Linux system administration for a group studying protein identification techniques.

2. [2002] Head of digital services for the University of Alabama's libraries.

3. [2000] Business analyst consultant for Pfizer, Inc. involved in a Laboratory Information Management System for Pfizer's Worldwide Pharmaceutical Sciences Division.

4. [2003] Works at International Paper Co. developing report designs and data representation. Uses multiple software tools such as Cognos and SAP BW and applies a knowledge of UNIX and scripting. Expresses gratitude for knowledge gained in the Information Retrieval course at UT.

PhD Degree Graduates

1 .[1996] Employed by Intel Corp. as a Parallel Applications Engineer (Parallel applications are done by separating a calculation into smaller parts that can be run simultaneously. This makes it possible for computers to run with less heat generation.)

2. [1998] Employed at the University of California, San Diego as a researcher at the Supercomputer Center, as an Adjunct Assistant Professor in the Computer Science and Engineering Department, and as the Director of the Grid and Research Innovation Laboratory there.

3 [1999] Assistant Professor of Computer Science at Jackson State University. (Of interest is that when he came to Jackson State, there was a great shortage of faculty, and now there are 9 graduate faculty members.) Active in building the department and interested in research in bioinformatics.

4 [1999] Assistant Professor at Maryville College (a small liberal arts college) teaching undergraduate computer science courses.

5. [1998] Currently a postdoctoral fellow at UCLA at a molecular imaging institute in the David Geffen School of Medicine. Developing hardware and software imaging systems for small animals. Notes the highly competitive atmosphere because of the reputation of the school of medicine that attracts investigators from many countries.

6. [1994] Associate Professor at Northeastern State University

VITA

Melvin L. Tobias was born in Brooklyn, NY, the son of Jacob and Gertrude Greenberg Tobias in 1925. He attended public schools in that city and was a graduate of Townsend Harris High School, the preparatory school for City College of New York, in 1940. He graduated from the City College of New York in 1944 with the degree of Bachelor of Science in Chemical Engineering. After a term of military service in the army, he attended the University of Minnesota starting in 1946, attaining a doctoral degree in Chemical Engineering with a minor in Applied Mathematics in 1950 under Prof. Arthur Stoppel as major advisor. In October of that year, he joined Oak Ridge National Laboratory in Oak Ridge, TN, where he served as a Research Staff Member in that institution's Engineering Technology Division until his retirement in 1993. He is now continuing as a graduate student at the University of Tennessee in Knoxville, pursuing studies in the field of Economics.