Chapter 1: Introduction

> The dominant position of the United States depended substantially on our own strong commitment to science and technology and on the comparative weakness of much of the rest of the world. But the age of relatively unchallenged U.S. leadership is ending.
>
> -- National Academy of Sciences[1]

Science is of tremendous importance today. It has long been valued not only for its own sake as knowledge of the natural world, but also for its direct contributions toward improving countless aspects of human life, such as the availability of food, water, housing, and material goods, health, education, communication, transportation, and security from natural disasters, epidemics, and human warfare. Closely related to science is technology, which is sometimes considered synonymous with applied science. Although it is not easy to pin down precisely what the economic impact of technology is in any given society, there is little controversy over the general sentiment that "technological change -- improvement in the instructions for mixing together raw materials -- lies at the heart of economic growth."[2]

The crucial role of science in an economy is widely recognized and acknowledged.[3] Indeed, the increasing importance of science is a major reason for characterizing today's society as a "postindustrial society," and today's economy as a "knowledge economy."[4] While social scientists may debate how to accurately assess the economic returns to national investment in science and technology, policy-makers and the public are in complete agreement regarding the importance of science and science-based technology as an economic engine.[5] Sixty-nine percent of Americans believe that scientific research is

---

[1] National Academy of Sciences, National Academy of Engineering, and Institute of Medicine (2007, p.206).

[2] Romer (1990, p.S72); also see Diamond (1999), Homer et al. (2008), National Academy of Sciences et al. (2007, 2010), and Solow (1957).

[3] Ben-David (1971); Price (1986).

[4] Bell (1973) and Rooney, Hearn, and Ninan (2005).

[5] Neal, Smith, and McCormick (2008).

"very important" to the U.S. economy,[6] and most introductory macroeconomic textbooks follow the work of Robert Solow, who presents technological change as the primary mechanism by which economic growth can be sustained.[7]

Science and technology are the results of human activity. While practiced by individual scientists, they can have a large impact on a society. Thus, the importance of scientists in today's world is not a matter of contention. To sustain economic growth in the modern age, any society, including the United States, must possess a large and talented scientific labor force. The recent global economic crisis that began in 2008 has intensified public awareness of the critical importance of technology, as policymakers, desperate for solutions, increasingly turn towards scientists and engineers for solutions to economic problems. "America's economy is in crisis," said former U.S. Senator Edward Kaufman on the Senate floor in February of 2009. "We can either drown under the weight of the problem, or we can surf the wave of opportunity that it brings – to put science, engineering and innovation back in their rightful place in our economy."[8]

One reason why technological change has had a dramatic effect on past economic growth and may have an even more dramatic effect in the future, is a unique feature of scientific knowledge in general: such knowledge can, with little effort, be shared at virtually no additional cost to either those who produced the knowledge or those who adopt it.[9] Although most published materials and inventions are legally protected, scientists have a long tradition of sharing scientific ideas freely with one another

---

[6] Research! America (2007).

[7] Solow (1957). Although Solow's model may be considered simplistic for assuming technological change to be exogenous, more recent efforts have aimed largely at refining his approach rather than challenging the basic premise that technological change is central to economic growth. See also Mankiw (2003).

[8] Kaufman (2009).

[9] Economists call this type of good a "nonrival good" (Romer 1990; Warsh 2006).

through journal articles, books, conference presentations, unpublished papers, and, more recently, over the Internet.[10] Good ideas are shared, bought, copied, emulated, leapfrogged, and sometimes even stolen.

Thus, in satisfying their own thirst for knowledge and pursuing scientific activities, scientists as a group exert an enormous positive impact on their societies.[11] For this reason, many policy makers believe that it is both legitimate and economically rational for governments to subsidize scientists' work. While scientists may benefit directly from such subsidies, spillover effects to the larger society may well justify the cost. Hence, support of science is different from other types of government support that mainly help the beneficiaries. As a common expression goes, "Give a man a fish, and you have fed him for today. Teach a man to fish, and you have fed him for a lifetime." Science and technology are like knowledge of fishing: once distributed, they can feed many people for life. In providing economic wellbeing to their people, scientists in many countries, including those in the developing world, do exactly that.

While science is an occupation for those individuals who practice it, it is not just any occupation. Although a scientist is usually rewarded for his/her scientific achievements, the true beneficiary of the work is not just the individual researcher but the whole of humanity, which receives countless direct and indirect benefits from science through complex and varied pathways. For this reason, all industrialized countries are concerned with the condition of science and its practitioners – scientists – within their borders. In this book, we will examine scientists within the contemporary U.S. context, asking who our scientists are, who is most likely to become a scientist, and how American scientists as a group are faring.

---

[10] Concern over scientists having unequal access to journal articles has led, in recent years, to the creation of online repositories such as PubMed Central in medicine, CiteSeer^x in computer and information science, and arXiv in Physics.

[11] Economists call such effects "externalities" or "spillovers" (Mankiw 2003; Pindyck and Rubinfield 2005).

The Debate: Is American Science in Decline?

The twentieth century was "The American Century."[12] By the end of the century, America had become the world's only superpower, leading the world in many areas. Much of America's economic prosperity and world power has been derived from America's leadership in science and technology throughout most of the twentieth century.[13] Defying a Japanese historian's bold prediction in 1962 that "the scientific prosperity of [the] U.S.A., begun in 1920, *will* end in 2000,"[14] American science is still going strong today.

Comprising only 5 percent of the world's total population, the United States can claim responsibility for one-third to two-thirds of the world's scientific activities and accomplishments on most measurable indicators. For example, in the world today, the United States accounts for[15]

(1) 40 percent of total research and development spending;

(2) 38 percent of patented new technology inventions by the industrialized nations of the Organization for Economic Cooperation and Development (OECD);

(3) 45 percent of the world's Nobel Prize winners in physics, chemistry, and physiology or medicine through year 2009;[16]

(4) 35, 49, and 63 percent, respectively, of the world's scientific publications, citations, and highly cited publications;

(5) 75 percent of the world's top 20 and 58 percent of the world's top 100 universities.[17]

---

[12] Goldin and Katz (2008); National Academy of Sciences et al. (2007).

[13] Ibid.

[14] Yuasa (1962, p.70, emphasis added).

[15] The following statistics came from Galama and Hosek (2008), except the one for Nobel Prize winners.

[16] Our calculation is based on data from Wikipedia (2010) and Nobelprize.org (2010). Note that this number is lower than the 70 percent cited by Galama and Hosek (2008, p.xvi) and the 60 percent since the 1930s cited by Cole (2009, p.4) because we restricted ourselves to Nobel Prizes awarded only in the three science fields of physics, chemistry, and physiology/medicine. Americans' share of winners of the Nobel Prize in Economics is much higher.

[17] Also see Cole (2009).

Individually, these statistics are measured with error and may not necessarily be accurate indicators of America's contribution to science. Taken as a whole, however, they are persuasive in presenting the United States as the continuing, unchallenged world leader in science, technology, and innovation. No other country has reached levels on these indicators anywhere near those of the United States,[18] as American scientists themselves seem to realize. In a survey conducted in 2009 by the Pew Research Center and the American Association for the Advancement of Science, 49% of the American scientists surveyed rated America's scientific achievements as "best in the world" and 45% as above average compared with those of other industrialized countries.[19] In addition, 88% of the same group believed that U.S. achievements in their own specialties were either the best in the world or above average.[20]

While most experts agree that U.S. science is dominant at present, many researchers – as well as policy makers and the general public – have become less confident regarding its future prospects. Questions have been raised not only as to whether the U.S. can sustain its leadership in science in the future but also as to whether the U.S. actually overestimates its current strength in science relative to that of other countries.[21] One recurrent concern is over the potential shortage of scientists in the U.S., a debate that has surfaced from the end of World War II to the present, beginning in the 1950s in response to Sputnik and reappearing in the 1980s as national concern with mathematics and science education grew. In 1990, former University of California President and National Science Foundation (NSF) director Richard Atkinson, in a well-publicized article in *Science* magazine, predicted " 'significant shortfalls' of scientists in the near future" and declared this "a national crisis."[22] In another issue of *Science* the same year, Philip Abelson, famous for his joint discovery of neptunium with Edwin McMillan, linked

---

[18] IMD International (2005); Adams (2007).

[19] Pew Research Center (2009a). The sample was 2,533 members of the American Association for the Advancement of Science (AAAS), 81% U.S. born, 9% foreign-born U.S. citizens, and 9% non-citizens.

[20] Pew Research Center (2009a).

[21] Hollingsworth, Müller, and Hollingsworth (2008).

[22] Atkinson (1990). See also Grogan (1990). Atkinson's *Science* article has been widely criticized, and he himself later admitted that some of its assumptions were flawed, especially where immigration was concerned (Atkinson 1996).

excellence in science to the overall well-being of a nation. “In the future global competition,” he wrote, “a country not tops in chemistry is destined to be second-rate or worse.”[23] Note that these two quotes embody two distinct but related claims: that of an impending shortfall of American scientists and that national well-being depends on scientific dominance. For simplicity, we call such sentiments the “alarmist view.” This view has been widely shared, as well as criticized, by observers and commentators.[24]

The alarmist view was recently embodied in a highly profiled 2007 report issued by the National Academy of Sciences (NAS), the National Academy of Engineering, and the Institute of Medicine, entitled *Rising above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*. The report was drafted by the Committee on Prospering in the Global Economy of the 21st Century, organized in 2005, in response to a bipartisan congressional request to assess the current state of American science, identify urgent challenges, and recommend steps to be taken to make sure that the U.S. retains its scientific leadership. The report, released a mere ten weeks after the committee's first meeting, emphasized the economic importance of science and engineering. While it maintained that the United States is still the “undisputed leader in the performance of basic and applied research” as well as in applying scientific advances in improving the state of the economy, the authors expressed concern that the present state of affairs may not continue, due both to science being on the rise in other countries and to inadequate national investment by the U.S. in educating scientists and supporting them in their endeavors. Failing to keep up scientifically may have devastating effects not only on the economy, the authors said, but also on public health, the environment, national security, and other aspects of American life. The report’s recommendations focused on improving K-12 education, investing in long-term, basic scientific

---

[23] Abelson (1990).

[24] While concern over an inadequate scientific labor force in the U.S. goes back to the 1950s (e.g., Mead and Metraux 1957), the current “crisis” debate received widespread attention beginning in the 1990s. See Neal, Smith, and McCormick (2008, pp.277-293) for a recent review of the debate on the shortage of scientists and engineers in the U.S. amounting to a possible crisis.

research, and creating environments for research and innovation that will attract and retain the best and brightest students in the world.[25]

This report received a great deal of attention from policy makers, spawning over two dozen bills in Congress within a year of its release. Several indicators, in both education and the labor force, do seem to validate its concerns. In education, an increasingly large share of U.S. science degrees, especially at the Ph.D. level, go to persons who were born abroad (as we discuss in Chapter 8). American high school students' performances on certain mathematics tests have been interpreted as mediocre by international standards in recent decades, suggesting that they may be ill-prepared for advanced scientific training.[26] In the labor force, the rising share of immigrants among practicing scientists and engineers indicates that America's dependence on foreign-born and foreign-trained scientists has dramatically increased.[27] Furthermore, science and engineering have been criticized for low rates of participation among women and minorities, which can be viewed as a problem of both inequality and under-utilization of talent.[28] A recent report under the auspices of the National Academy of Sciences urged efforts to increase the participation of non-white, non-Asian U.S. citizens in science as a way to increase both the diversity of perspectives represented in science and the supply of native-born American scientists in case the recruitment of immigrant scientists to the U.S. becomes more difficult in the future.[29]

However, the concerns expressed by the authors of the original NAS report and others did not go unchallenged. Scholars at RAND responded to the report by holding a major conference, followed first by

---

[25] National Academy of Sciences, National Academy of Engineering, and Institute of Medicine (2007).

[26] This is to be discussed in Chapters 3 and 7.

[27] Freeman (2006) reports that in 2000, 39% of science and engineering Ph.D.s went to individuals born outside of the U.S. Matthews (2008), in an issue brief for the Congressional Research Service, reports that in 2005 foreign students earned 34.7% of doctorates in science and 63.1% of those in engineering. Students on temporary visas, 56% of whom remain in the U.S., earned 30.8% of science and 58.6% of engineering doctorates. We will discuss this topic in Chapters 5 and 8.

[28] National Science Foundation (1986, p.iii).

[29] National Academy of Sciences (2011, Chapter 1).

the publication of the proceedings[30] and, the following year, by a more unified report[31] which, while acknowledging some areas of concern, such as the relatively low test scores in mathematics and science of U.S. K-12 students, challenged the NAS report's claim that science in the U.S. is experiencing a "creeping crisis" as well as its "clarion call" for drastic action to save America from the devastating effects of scientific and technological decline. Dire warnings issued in the 1980s and 1990s, the RAND report pointed out, were not followed by the anticipated catastrophes, and thus it is important to evaluate the data carefully. The RAND report specifically challenged the notion that globalization of science and technology and increased capabilities of other countries are inherently harmful to the U.S., arguing, instead, that these trends may be beneficial.[32]

Along with the authors of the RAND report, other scholars maintained that the state of American science and/or science education was less worrisome than the NAS authors had claimed. In a working paper published in 2007 by the Urban Institute, Lowell and Salzman attacked the NAS report using data from the National Assessment of Educational Progress (NAEP), the math portion of the Scholastic Aptitude Test (SAT), the Trends in International Mathematics and Science Study (TIMSS), and the Program for International Study Assessment (PISA), painting an overall picture of U.S. math and science education as healthy and steady.[33]

Moreover, economic studies have found little direct evidence of a *market* shortage of scientists practicing in the United States.[34] We will provide our own analysis on the issue later in this book, showing that, in recent decades, growth in the scientific labor force has outpaced growth in the general labor force, and scientists' earnings have not grown relative to those in other professions, as we would expect in the case of a shortage. In fact, erosion in the economic rewards to science as compared to those

---

[30] Galama and Hosek (2007).

[31] Galama and Hosek (2008).

[32] For a critique of the RAND report, see Ezell and Atkinson (2008).

[33] Lowell and Salzman (2007).

[34] Butz et al. (2003). Later in the book, we will also show empirical evidence consistent with this claim.

to other professions, due both to falling relative wages and increasing career launching time for scientists, has led some scholars to assert that, while America may face a scientific crisis, it is a problem of low demand rather than a low supply.[35] An article that appeared in *Miller-McCune* in 2010 challenged the NAS report by pointing to the current insufficiency of jobs for qualified scientists, citing an earlier (2005) NAS report entitled *Bridges to Independence: Fostering the Independence of New Researchers in Biological Research*, which described a "crisis of expectation" among young scientists frustrated by the lack of career opportunities. The 2010 *Miller-McCune* article also cited a finding that only a third of the Americans earning degrees in science and engineering each year are able to find work in their fields. In contrast to the alarmist shortage view, this perspective instead suggests an oversupply of young scientists compared to the demand for scientists in the workforce.[36] We will discuss this aspect of the debate more fully in Chapter 9.

Despite these criticisms, the main message of the NAS report that America needs more and better science has resonated well among business leaders and politicians. A report released by the Education for Innovation Initiative in 2008 described business leaders as being concerned about the lack of policy action to maintain scientific leadership in the U.S.[37] In his address to the National Academy of Sciences in April, 2009, President Barack Obama declared unequivocally that the nation had fallen behind in science, at least in terms of its investments:

> A half century ago, this nation made a commitment to lead the world in scientific and technological innovation; to invest in education, in research, in engineering; to set a goal of reaching space and engaging every citizen in that historic mission. That was the high water mark of America's investment in research and development. And since then our investments have

[35] Austin (2002); Garrison, Stith, and Gerbi (2005); Teitelbaum (2002).

[36] Benderly (2010); National Research Council (2005).

[37] Education for Innovation Initiative (2008).

> steadily declined as a share of our national income. As a result, other countries are now beginning to pull ahead in the pursuit of this generation’s great discoveries.[38]

The President's remarks heralded a large infusion of federal funds into scientific research as part of the American Recovery and Reinvestment Act of 2009. The scientific community welcomed President Obama’s commitment to science and technology.[39]

Meanwhile, the criticism of the original NAS report did not persuade its authors to reverse their earlier claims. In fact, the authors reaffirmed their alarmist view in a follow-up report in 2010, declaring that “our nation’s outlook has worsened” and describing the “gathering storm” as now “rapidly approaching Category 5.”[40] This report discusses changes since 2005 (when the original report was being drafted) that are likely to have a negative impact on the competitive status of American science in the future. These include the continued growth and greater investment in science in other countries; the global economic downturn, leaving less money available in the federal budget to address the challenges of American science; and the financial crises of America’s universities. The new report concludes with a chapter on “The Ingredients of Innovation” in which, based on data gathered since the 2007 report, it maintains that American science is now in even greater peril than it was in before.[41]

In evaluating the claims of the alarmists versus those of their critics, it is relevant to recognize that any changes to national science policy would have differential impacts on different interest groups. For example, an increase of scientists would be beneficial to the business sector, which could then enjoy the productivity of scientists at lowered labor cost, but would intensify competition for employment among individual scientists and thus lead to the worsening of their labor force outcomes. We note that the committee that produced the 2007 NAS report included not only university presidents, Nobel Prize

---

[38] Obama (2009).

[39] Cicerone (2009).

[40] National Academy of Sciences (2010, p.4). The subtitle of the report is: “Rapidly Approaching Category 5.”

[41] National Academy of Sciences, National Academy of Engineering, and Institute of Medicine (2010).

winners, and former presidential appointees, but also a few former corporate CEOs. Their critics, in contrast, have often been academic economists who are keenly aware of a perennial shortage of tenure-track positions relative to the number of aspiring young scientists.

Whether or not America is headed for a catastrophic shortage of scientists, it would be difficult to deny at least some degree of vulnerability in this respect today. American science and technology could be damaged if the flow of immigrant scientists should stop or dramatically decline, or if falling wages for scientists should begin to deter American-born youth with talent in science from pursuing scientific careers. Given the potential risk to our economy and national security, it is prudent to ask whether there is a current shortage of scientists in America today, or if America is in danger of experiencing a shortage of scientists in the near future. The alarmist view -- that there is now or soon will be a shortage of scientists in America -- is essentially a proposition about social trends. That is, the current period is viewed as a disappointing departure from a past era in which American science enjoyed unquestioned glory. At least according to some observers and commentators, Americans' lack of interest in science represents a cultural change from the era immediately following World War II, when American society as a whole became fascinated with science following the Soviet Union's launching of Sputnik.[42] Hence, to assess the alarmist view, it is important that we examine empirical data that pertain to changes concerning scientists and potential scientists in the last few decades in America. Fortunately, a wealth of data have been collected by government agencies and research organizations that can be mined and brought to bear on the research questions of whether -- and why -- only small numbers of American youths pursue scientific careers. In this book, we present our analyses and interpretations of these data.

In the final analysis, how optimistic or pessimistic one is regarding the future of American science may depend on what criteria one chooses for evaluating its many different aspects. In judging the health of science as a profession, researchers have looked at the performance of K-12 students on mathematics and science tests, the percentage of freshmen planning to major in science or engineering,

[42] Kevles (1977b); Neal, Smith, and McCormick (2008).

graduate enrollments and doctorates awarded in science and engineering, rankings of research institutions, number of employed scientists, number of publications, number of patents applied for or awarded, number of papers listed in the Science Citation Index, number of Nobel Prize winners, percentage of the Gross Domestic Product spent on research and development, public and media attitudes towards science, percentage of immigrant scientists, and a host of other factors. In this book, our primary focus will be on the number of employed scientists in the U.S. and on those factors that influence the process of becoming a scientist, such as the rewards scientists receive for their work, the individual characteristics of those recruited into science, cultural attitudes toward science, and the quality and availability of scientific education. Of course, we are under no illusion that a thorough understanding of these factors will necessarily enable us to resolve, once and for all, the debate over whether American science will continue to thrive or decline. As we shall see, American science may be robust by some indicators but face a potential decline by others. Thus, in this book, we hope to move beyond black-and-white generalizations about the health or decline of American science towards a more nuanced, but more accurate, assessment based on the full complexity of its various aspects.

Definitions of Science and Scientists

To address the question of whether or not a sufficient number of youths in contemporary America are attracted to scientific careers, we need first to define both "science" and "scientist." By "science" we refer to a special kind of knowledge that is generated and verified through the use of standardized methods and that involves systematic experimentation and reasoning, often with the help of technology and/or mathematics.[43]

---

[43] This is sometimes referred to more precisely as "mature science" or "modern experimental science," in contrast with methods of studying nature in ancient cultures and in medieval universities. The word "science" also historically meant general knowledge and skill, particularly in medieval times (Oxford English Dictionary 2009). While our definition concurs with the commonplace understanding of science, some historians of science have cautioned that there has never been a coherent notion of science even among practicing scientists. For example, Shapin (1996, p.3) defines science merely as "diverse arrays of cultural practices aimed at understanding, explaining, and controlling the natural world" without reference to methods.

Two definitions of "scientist" are common in the literature: (1) the behavioral (occupation-based or demand-based) definition; and (2) the credential (education-based or supply-based) definition.[44] In practice, the occupation-based definition specifies that the incumbents of scientific occupations are scientists. The education-based definition considers individuals with or working toward science degrees as scientists or potential scientists.

In this book, we use both definitions. When we discuss trends in employed scientists, we make use of the occupation-based definition. When, however, we examine scientific pipeline issues – questions of how individuals progress through the various stages of scientific education and from education to scientific careers – we study science education and thus invoke the education-based definition. Operationally, we include engineers, computer scientists, and medical scientists as part of the definition but exclude medical doctors, computer programmers, technicians, and social scientists. Our choice to exclude the latter groups is based on the interest in the literature in the potential shortage of native-born scientific talent in the hard sciences.[45] Whenever possible and meaningful, we conducted our statistical analyses of scientists in the labor force and potential scientists in the educational pipeline focusing on four major fields: biological science, physical science, mathematical science, and engineering.[46] Note that computer science is considered part of mathematical science for most of the analyses, although we sometimes analyze this group separately.

A Preview of Chapters

The main objective of this book is to assess the health of science in America. However, an informative assessment is not a simple matter in this case, as "American science" is not a monolithic entity. Such an assessment requires multiple indicators that may reveal different trends. Understanding the nature of this heterogeneity is important, as this can help policy-makers to design programs to promote American

[44] Citro and Kalton (1989); Xie and Shauman (2003).

[45] The decision to exclude social science had important consequences for the study, as shown in Chapters 8 and 9.

[46] On the website for this book, we provide detailed codes that we use to define scientific occupations and science education by major field, for all data sets that we use.

science more effectively. Therefore, in each chapter we examine American science from a different perspective, providing a more comprehensive view than can be achieved through inspection of only a single indicator.

The present chapter, Chapter 1, is our introduction. In Chapter 2, we provide an overview of the development of science as an occupation and the evolution of American science since 1900. In Chapter 3, we shift from a historical overview to a spatial one, placing American science within the context of a globalized world and comparing it with science in other countries in terms of several different indicators. Chapter 4, a theoretical discussion of scientific career choice, provides the foundation for the rest of the book, which is divided into empirical studies of three types of trends in the U.S. between 1960 and 2000: characteristics of the scientific labor force, societal support for science, and the supply of potential scientists. In Chapter 5, we study the demographic and economic characteristics of the American scientific labor force, presenting a portrait of its changing composition using data from the U.S. Census over the period 1960-2000 and the American Community Survey 2006-2008. In Chapter 6, we shift our focus to public attitudes, documenting trends in Americans' perceptions of and attitudes toward science since the 1970s. In Chapter 7, we describe trends in youths' expectations of scientific study. In Chapter 8, we assess trends in scientific education, examining scientific degree production and attainment at American institutions. In Chapter 9, we document trends in the transition from scientific education to scientific occupations. Finally, in the conclusion, Chapter 10, we summarize our findings and explore their overall significance.