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Executive Summary

Purpose

To help inform policy decisions by the U.S. Government concerning the admission of foreign students and workers to the United States, the Office of Science and Technology Policy (OSTP) asked the Science and Technology Policy Institute (STPI) to provide a comprehensive, empirically-based comparison of the potential economic benefits and costs to the United States related to foreign science, technology, engineering, and mathematics (STEM) talent who visit, work, or study in this country. This report provides quantitative estimates and a net assessment of those economic benefits and losses. It is designed to assist in the formulation of effective policies to reduce economic losses associated with the misappropriation of U.S. trade secrets to competitor countries, in particular China, while preserving the benefits of foreign STEM talent to the United States.

Introduction

Innovation is a major driver of economic growth and an important determinant of national security. Scientists, engineers, mathematicians, entrepreneurs in technology industries, and other members of the STEM community have been the primary sources of innovation. Many of these individuals were born outside the United States: in 2018, foreign-born talent comprised 28 to 30 percent of the U.S. STEM workforce. Foreign STEM talent is likely to continue to play an important role in U.S. innovation as the majority of students in many U.S. STEM graduate programs are foreign students.

Despite the contributions of foreign STEM talent to the United States, concerns have been voiced about the large numbers—including those from China—employed in innovation activities in U.S. companies, laboratories, and academic institutions. These individuals are seen as posing risks of misappropriating U.S. trade secrets from important U.S. industries, transferring them to companies in competitor countries. They may also return to their countries of birth with intangible technology that they have acquired in the United States. They may potentially displace U.S-born talent for jobs and educational opportunities.

Methodology

For our assessment, we divided the community of interest into five categories: short-term visitors to the United States with STEM backgrounds; foreign-born STEM workers; post-doctoral fellows and visiting STEM researchers from other countries; foreign STEM doctoral students; and foreign students in U.S. bachelor's and master's programs. To assess the importance of foreign-born STEM talent for the U.S. STEM workforce today and its likely importance in the immediate future, we reviewed statistical data on the size of this workforce and on the role of foreign students in U.S. undergraduate and graduate programs. We then drew on a range of U.S. national income accounting data, information on foreign-born entrepreneurs, and statistics about foreign students to estimate the economic benefits of foreign STEM talent to the United States. Subsequently, we estimated the costs of misappropriation of U.S. trade secrets by foreign STEM visitors, students, and workers in the United States and from U.S. academic fraud associated with China. We also examined potential economic losses to the United States from intangible technology transfers (ITT) by foreign STEM talent who return to their home country. As part of that examination, we reviewed estimates of gross job losses over the last few decades in the United States attributed to competition from China. We conclude by estimating net benefits and costs to the United States for the five classes of foreign STEM talent in the United States.

Economic Benefits of Foreign-born STEM Talent Working in the United States

We found that foreign-born workers account for a substantial share of the U.S. STEM workforce—28 to 30 percent. Foreign-born STEM doctorates comprise an even higher share of the STEM doctoral workforce—44 percent. Foreign students, students who attend U.S. colleges and universities on temporary visas, account for approximately one-third of new STEM doctorates. In some fields, such as computer science and mathematics, over half of all people receiving doctorates from U.S. universities are non-U.S. citizens on temporary visas. Most of these STEM doctorates remain in the United States after completing their degrees. Approximately 77 percent of graduating foreign doctoral students say they would like to remain in the United States to work. For foreign doctoral students from China and India graduating from U.S. universities, stay rates are even higher—83 percent of such individuals from both nations stay in the United States for at least 5 years following graduation. Hence, foreign students are likely to remain an important source of new entrants to the U.S. STEM doctoral workforce.

The United States gains substantial economic benefits from foreign STEM talent who work or study in the country. In 2019, the average STEM worker, including foreign-born STEM workers, contributed $139,605 in value-added to U.S. Gross Domestic Product (GDP). In aggregate, the foreign-born STEM workforce contributed $367 billion to $409 billion in labor value-added, 1.7 to 1.9 percent of U.S. GDP in that year. Foreign-born STEM workers and foreign doctoral students increase U.S. total factor productivity through their contributions to innovation. We estimate that in 2019 on a per capita basis each foreign-born STEM worker and foreign doctoral student contributed from $12,225 to $13,568 to U.S. GDP. Foreign-born entrepreneurs have helped found U.S. companies in

R&D-intensive industries; the value-added from these companies is estimated to range from $260 billion to $394 billion, or 1.2 to 1.8 percent of GDP. We estimate that in 2018 foreign STEM students spent $21.7 billion on tuition, room and board, and other costs for educational purposes in the United States.

Costs of Misappropriation of U.S. Trade Secrets by Foreign STEM Talent in the United States

Several organizations have highlighted economic costs to the United States inflicted by foreign countries—including China—through copyright, trademark, and patent infringements and misappropriation of trade secrets. We did not find that foreign STEM talent in the United States is a critical factor regarding infringements of U.S. copyrights, trademarks, or patents. Individuals and organizations in the home countries of foreign STEM talent perpetuate those activities; they do not need to be physically present in the United States to do so.

We employed the results of a survey of U.S. businesses to estimate aggregate losses to the U.S. economy from the misappropriation of U.S. trade secrets. We did not use the larger estimates of losses associated with misappropriations of U.S. trade secrets cited by several studies, which can run in the hundreds of billions of dollars. These estimates appear to assume that losses to the United States from the misappropriation of trade secrets equal the cost to the company of developing the technology. Technologies are non-rival: even if the technology has been stolen, the original owner can still use it. Losses only ensue if the original owner loses revenues because the thief has used the stolen trade secret to manufacture a competing product or has sold it to someone who does.

We used a database of U.S. court cases involving Chinese violations of U.S. intellectual property rights assembled by the Center for Strategic and International Studies to estimate the potential value of misappropriated trade secrets per instance of theft. We divided entries in the database among those that involved foreign STEM talent in the United States who physically acquired the secrets, cybercriminals located outside the United States, and other avenues for theft. Based on these data, we found cybercrime to be the most important avenue for misappropriating U.S. trade secrets.

Costs of Intangible Technology Transfers by Foreign STEM Talent in the United States

One of the concerns voiced about foreign STEM students who study in the United States, especially in doctorate programs, and foreign-born STEM workers is the transfer of intangible technologies—know-how stemming from what they have learned about processes, procedures, and operations through working or studying in the United States—to their country of origin. Especially in high or emerging technology industries, ITT may be a prerequisite for creating a new industry. Foreign STEM talent can impose an economic cost to the United States if the individual transfers intangible technology and the ITT contributes to the emergence of a new industry that competes with an existing or emerging U.S. industry, resulting in declines in U.S. output or employment.

Technology transfer is an important factor in the rise of new industries. Imports of foreign machinery; advice from suppliers, customers, and industry consultants; foreign direct investment; and movements of workers who have acquired skills in new technologies from foreign companies to domestic companies play major roles in the establishment of competing industries. ITT has played an important role in the development of high technology industries in India, South Korea, and Taiwan. Chinese nationals who have returned from studying or working abroad have played helpful roles in several emerging industries, but in general the role of ITT has been secondary to other factors in many of the industries in China that have rapidly taken global market shares. In addition to technology transfer through all avenues, not just ITT, many Chinese industries that have become competitive with those in the United States have benefited from increased economies of scale stemming from China's large domestic market: its lower-cost, increasingly productive labor force and its highly efficient supplier networks have been major factors in the growth.

Because of the difficulty in determining the role of ITT in the growth of competing industries in China, we were unable to generate estimates of losses to the United States from ITT. We did review the loss of U.S. manufacturing jobs tied to competition from Chinese imports, a consequence of the emergence of competing Chinese industries. Although on a net basis, the United States gains economically from trade with China, these losses have been a major social, economic, and political issue. A number of economists have estimated gross losses in manufacturing jobs over the last few decades linked to U.S. imports from China, ranging from 0.2 million to 2.4 million jobs. These losses are indirectly linked to technology transfer, including ITT.

As a proxy for losses tied to ITT, we estimated the value the Chinese government ascribes to STEM returnees. Using the Chinese government's willingness to pay these individuals higher salaries through the Thousand Talents programs, we estimate the value the Chinese government places on ITT from a STEM professional with less than 5 years of experience in the United States is around \$110,000 per year and the value of an individual with more experience is about \$170,000.

Net Benefits

Using our estimates of benefits and costs, we estimate the net benefits of foreign STEM talent in the United States for the five classes of individuals. We found that travel expenditures by short-term visitors substantially outweigh potential losses from the misappropriation of trade secrets by these individuals. Foreign-born STEM workers are enormously economically beneficial to the United States: we estimate net benefits range from approximately $200,000 to $700,000 per individual in this group over a 3-year period on a net basis. Post-doctoral fellows, visiting researchers, and graduating doctoral students also benefit the United States economically on a net basis.

Benefits and Costs of Foreign STEM Talent for U.S. National Security

Benefits

Foreign-born STEM talent provides benefits to U.S. national security, although we were unable to quantify these benefits. Foreign-born STEM talent is an important, if untabulated, component of the U.S. defense industry workforce. Naturalized U.S. citizens work in STEM occupations in U.S. Government laboratories and agencies as well as companies that serve the Department of Defense and U.S. intelligence agencies, providing substantial value-added, ideas, and inventions to the United States national security establishment. These and other foreign-born STEM talent, who may or may not be citizens, work in industries that produce dual-use technologies, contributing to U.S. national security by keeping the United States on the technological frontier.

Costs

Costs to U.S. national security from the loss of information on U.S. weapon systems are high, as the costs of developing and manufacturing these systems can run into the tens or hundreds of billions of dollars. Access to classified designs and other knowledge about these systems makes it easier for adversaries to design countermeasures or build similar systems, forcing the United States to invest in countering these adversary systems. Both native- and foreign-born U.S. citizens have stolen and sold secrets to foreign adversaries. As only U.S. citizens with security clearances have access to these secrets, these crimes reflect the failure of U.S. security systems as well as the disloyalty of the thief. Both native- and foreign-born citizens have been accused of misappropriating trade secrets from U.S. companies for which they have worked, including from companies developing dual-use technologies with national security implications. We were unable to determine whether foreign-born STEM talent is more likely to have engaged in these activities than citizens born in the United States.

Foreign STEM students who study in the United States, especially in doctorate programs, and foreign-born STEM workers could potentially transfer to their countries of birth intangible knowledge about dual-use technologies. This issue has been of special concern for emerging technologies that may have national security implications, like quantum sensors, but are too nascent to be classified for national security reasons. Knowledge about these emerging technologies can be obtained from a wide range of sources (e.g., journals, trade shows, conferences, purchases of equipment), not just from foreign STEM talent trained in the United States. The extent to which ITT has played a role in developing adversary capabilities in dual-use technologies is unknown.

Contents

1. Introduction

A. Purpose

To help inform policy decisions by the U.S. Government concerning the admission of foreign students and workers to the United States, the Office of Science and Technology Policy (OSTP) asked the Science and Technology Policy Institute (STPI) to provide a comprehensive, empirically-based comparison of the potential economic benefits and costs to the United States related to foreign science, technology, engineering, and mathematics (STEM) talent who visit, work, or study in this country. This report provides quantitative estimates and a net assessment of those economic benefits and costs. It is designed to assist in the formulation of effective policies to reduce economic losses associated with the misappropriation of U.S. trade secrets to competitor countries, in particular China, while preserving the benefits of foreign STEM talent to the United States.

B. Background

Innovation is the introduction and diffusion of new solutions in response to problems, challenges, or opportunities that arise in society or the economy. It is an important driver of economic growth and determinant of national security (Romer 1990; Jorgensen 1988; House Armed Services Committee 2020). Scientists, engineers, mathematicians, entrepreneurs in technology industries, and other members of the STEM community have been the primary sources of innovation. Many of these individuals were born outside the United States: in 2018, foreign-born talent comprised 28 to 30 percent of the U.S. STEM workforce. Many of the founders or chief executive officers (CEOs) of U.S. high technology companies have been immigrants (Anderson 2018); surveys have found that 16 to 24.3 percent of high technology companies were started by foreign-born individuals (Hart and Acs 2011; Wadhwa et al. 2012).

Foreign STEM talent is likely to continue to play an important role in U.S. innovation. Many students in U.S. STEM graduate programs are foreign students. As an example, between 2014 and 2018, roughly two-thirds of all doctorates granted in electrical engineering went to foreign students, with one quarter of all doctorates in electrical engineering awarded to students from China (STPI's calculations based on custom tabulations provided by NCSES). Most of these STEM doctorates have remained in the United States after completing their degrees: over 70 percent of foreign students with doctorates in physics, engineering, computer science, and mathematics have stayed in the United States to work for 10 years or more after receiving their degrees (NSF 2020). In the case of STEM doctoral students from China, 83 and 90 percent have remained in the United States in the 5- and 10-years following graduation, respectively, although for recent doctoral graduates from China (in 2014–2017), a slightly lower percentage indicate that they intend to stay in the United States (NSF 2019).

Despite the contributions of foreign STEM talent to the United States, concerns have been voiced about the large numbers—including those from China—employed in innovation activities in U.S. companies, laboratories, and academic institutions. These individuals are seen as posing risks of misappropriating U.S. trade secrets from important U.S. industries, transferring them to companies in competitor countries. In particular, foreign STEM talent born in China who work and study in the United States are seen as a conduit for transferring U.S. technologies to China (Commission on the Theft of American Intellectual Property 2017). Foreign STEM talent may return to their countries of birth with intangible technologies that they have acquired in the United States that may be used to create industries that compete with those in the United States. Foreign-born workers and foreign students may compete with U.S-born talent for jobs and educational opportunities.

To reduce risks of technology transfer, Presidential Proclamation 10043, "Suspension of Entry as Nonimmigrants of Certain Students and Researchers From the People's Republic of China" was issued on May 29, 2020. The proclamation prohibits Chinese nationals who have studied or worked in institutions that support the People's Liberation Army or are engaged in China's "military-civil fusion strategy" from obtaining visas for graduate study or to conduct research in the United States.

To make informed policy decisions concerning access to the United States by foreign STEM talent, the U.S. Government would benefit from an empirically-based understanding of the extent of economic benefits and losses from these individuals. We note, for example, foreign STEM talent is not the only and likely not the primary means through which foreign adversaries engage in economic espionage and misappropriation of U.S. trade secrets. U.S. counterintelligence agencies have been focused on attempts by organizations in China to use the internet to steal trade secrets (NCSC 2018). This report addresses this issue by providing a nuanced look at both benefits and costs. It recognizes that benefits and costs vary by types of individuals: short-term foreign visitors to the United States with STEM backgrounds; foreign-born STEM workers; post-doctoral fellows and visiting STEM researchers from other countries; STEM doctoral students from other countries; and foreign STEM students in U.S. bachelor's and master's programs. Although this report addresses broader issues of foreign STEM talent, because China has been in the spotlight, it pays particular attention to China.

C. Qualitative Economic and Social Benefits and Costs

Despite the report's focus on providing quantitative estimates of benefits and costs, not all benefits and costs can be measured quantitatively. In this section, we highlight some of the qualitative benefits and costs of foreign STEM talent in the United States.

1. Benefits

Collaboration. Allowing foreign STEM talent into the United States, even for short periods, has encouraged research collaborations that benefit the United States as well as the rest of the world. A joint statement from the U.S. State Department and U.S. Department of Education (2021) notes that such collaborations support U.S. diplomatic initiatives, by creating person-to-person connections and developing mutual understanding between cultures. These collaborations may be between current and emerging leaders within their research fields and within their respective governments.

"Brain Gain." The combination of an excellent research and development (R&D) enterprise and those policies that welcome top talent to come to the United States provides incentives for top talent from other nations to come to the United States and stay. Over the course of time, despite the bureaucratic hurdles, many succeed in converting from non-immigrant status to become permanent residents or citizens. For example, over the last decade, of the 2,800 individuals born in China who have presented their work at a NeurIPS—a well-known conference for AI researchers—over 2,000 were working outside of China, of which about 1,700 were working in the United States (Ma 2019). Ma explains this desire to stay as stemming from the U.S. research environment. He says, they stay "because most of the [Chinese] government resources went into expanding the talent base rather than creating incentives and an environment in which they stay (Ma 2019)."

2. Costs

Improves foreign industrial base. Allowing foreign students access to the U.S. education system results in those students who return home to obtain a somewhat better education than they could have otherwise gained. For instance, in the "Times Higher Education World University Rankings" (2021), the United States had 42 universities in the top 100, while China had only 6. Reducing or denying access to U.S. universities does not, however, stop foreign talent from going to highly regarded universities in other countries.

Encouraging licit cooperation can benefit the Chinese defense industrial base through a complex web of joint ventures between subsidiaries of Chinese non-defense universities and Chinese defense companies (Goldberg 2021). Through these joint ventures, Chinese defense companies can gain access to the intellectual property (IP) held by Chinese universities. Professors at universities may be dual-hatted as executives at companies with close ties to defense enterprises. Despite these close ties, the Mercatur Institute for China Studies (MERICS) has identified systematic problems with China's R&D environment, including rudimentary systems for project evaluation and widespread corruption (MERICS 2016). These issues may reduce China's ability to successfully take advantage of its expenditures on R&D. MERICS reports that "Chinese collaboration with foreign companies has not resulted in a lasting spillover effect in innovative capabilities" (MERICS 2016).

Potentially displace U.S. students. Some have argued that foreign students may crowd out U.S. students at U.S. universities. This does not seem to be the case. Research using data from the U.S. Department of Education's Integrated Postsecondary Education Data System (IPEDS), shows that "within 1,234 colleges and universities over 1990-2018, the number of international undergraduate students has no significant effect—either positive or negative—on the number of U.S. students enrolled" (Zavodny 2021). Zavodny's research also found that U.S. students "shift into STEM majors (science, engineering, computer science, and mathematics/statistics) from social sciences majors at schools that experience larger increases in the number of international [STEM and non-STEM] students." This is potentially due to the schools having more resources to devote to STEM programs. We are unaware of similar research regarding the potential displacement of U.S. graduate students. Remco Zwetsloot provides a brief literature review regarding "crowding out" of U.S. students and finds that the effect is most likely to happen at the doctoral and post-doctoral levels, though the evidence is mixed (Zwetsloot 2020).

D. Benefits and Costs of Foreign STEM Talent to U.S. National Security

In addition to the economic and qualitative benefits and costs to the United States that foreign STEM talent provides to or imposes on this country, foreign STEM talent may also provide benefits to and impose costs on U.S. national security. Like the qualitative economic and social costs discussed above, we were unable to put a dollar value on the benefits and costs of foreign STEM talent to U.S. national security. Below, we provide a qualitative discussion of some of these benefits and costs.

1. Benefits

Develop and manufacture defense technologies. Naturalized foreign-born STEM talent is an important, if untabulated, component of the U.S. defense industry workforce. Naturalized U.S. citizens work in STEM occupations in U.S. national laboratories, such as the Army, Air Force, and Naval Research Laboratories, the Department of Energy's national laboratories and in technology procurement and other STEM jobs in U.S. Government agencies. They also work in companies that serve the Department of Defense and U.S. intelligence agencies. These individuals provide substantial value-added, ideas, and inventions to the United States national security establishment.

Develop and produce dual-use technologies that contribute to U.S. national security. Foreign STEM talent plays an important role in U.S. R&D-intensive industries, accounting for an estimated 28.1 percent of the total U.S. STEM workforce. These individuals contribute to the development and production of dual-use technologies that keep the United States on the technological frontier and contribute to U.S. national security. In contrast to defense industries, where individuals working on classified systems must be U.S. citizens, a broad range of foreign STEM talent in the United States under several types of authorities work in industries that produce dual-use technologies.

Insights into and advantages vis-a-vis competitor countries. While foreign STEM talent who are not U.S. citizens cannot directly work on national security technologies, they can provide the U.S. Government with a clearer understanding of technical, social, and political developments in their home countries. In addition, foreign researchers working in the United States are not actively working for the defense industrial base of their country of origin.

2. Costs

Theft of classified information about U.S. weapon systems. The costs of developing and manufacturing U.S. defense and intelligence systems can run into the tens or hundreds of billions of dollars. The costs to national security of the loss of designs and other classified information about these systems are high, as adversaries use this information to design countermeasures or build similar systems. To counter adversary systems based on this knowledge, the United States may have to make substantial additional investments in new or revamped systems.

Only U.S. citizens with security clearances have access to classified information on U.S. defense and intelligence systems. The theft and sale of these secrets to foreign adversaries are serious crimes, which have been committed by both native- and foreign-born citizens. These crimes reflect the failure of U.S. security systems as well as the disloyalty of the thief. We did not have access to the full-range of known cases of this type of espionage, so were unable to determine their frequency or whether foreign-born STEM talent is more likely to have engaged in these activities than U.S. citizens born in the United States. Thus, we were unable to determine whether foreign-born STEM talent imposes costs over and above those imposed by U.S.-born citizens.

Misappropriation of trade secrets for dual-use technologies that contribute to U.S. national security. Both U.S.- and foreign-born STEM talent in the United States have been accused of misappropriating trade secrets from U.S. companies for which they have worked. Some of these trade secrets are from companies developing dual-use technologies that may have national security implications. It is not clear the extent of these thefts. We counted 57 instances over 20 years out of a set of 152 court cases involving the misappropriation of trade secrets in general, not just for dual-use technologies, for transfer to Chinese entities collected by the Center for Strategic and International Studies (CSIS) (CSIS 2021).

Intangible technology transfers (ITT) that might benefit U.S. adversaries. Foreign STEM students who study in the United States, especially in doctorate programs, and foreign-born STEM workers may potentially transfer to their countries of birth intangible technologies—know-how stemming from what they have learned about processes, procedures, and operations through working or studying in the United States—pertaining to dual-use technologies. This issue has been of special concern for emerging technologies that may have national security implications, like quantum sensors, but that have not reached a level of development whereby the U.S. Government can determine whether they need to be controlled for national security reasons. Knowledge, however, about emerging technologies can be obtained from a wide range of sources—such as journals, trade shows, conferences, and purchases of equipment—not just foreign STEM talent in the United States. The extent to which ITT has played a role in developing adversary capabilities in dual-use technologies is unclear.

E. Organization of This Report

Chapter 2 reviews the statistical data on the foreign-born STEM workforce in the United States and foreign doctoral students and graduates. The purpose of this section is to assess the importance of foreign STEM talent for the U.S. STEM workforce today and to comment on its likely importance in the immediate future.

Chapter 3 draws on a range of U.S. national income accounting data, information on foreign-born entrepreneurs, and statistics about foreign students to estimate the economic benefits of foreign STEM talent to the United States. We make estimates of labor value-added from foreign-born STEM talent, its contribution to growth in total U.S. factor productivity, economic contributions of foreign-born entrepreneurs, and tuition payments and expenditures on room and board by foreign students.

In Chapter 4, we estimate illicit costs that may be imposed by foreign STEM talent on the United States. The primary potential illicit cost posed by foreign STEM talent is likely to be misappropriation of trade secrets from U.S. companies. We employ the results of a survey of U.S. businesses to estimate losses from these thefts. We also estimate the costs of academic fraud associated with researchers obtaining research grants from both China and the United States for the same work.

In Chapter 5, we discuss the costs of ITT by foreign STEM talent who have studied or worked in the United States and return to their country of origin. We place ITT in the context of other factors that have led to the emergence of industries that compete with those in the United States. We also review estimates of the loss of U.S. manufacturing jobs tied to competition from Chinese imports. Because of the difficulty in determining the role of

ITT in the growth of competing industries in China, we were unable to generate estimates of losses to the United States from these transfers. We did estimate the value the Chinese government ascribes to ITT from returnees using the Chinese government's willingness to pay these individuals higher salaries through its Thousand Talents programs.

Chapter 6 estimates net benefits and costs to the United States for five classes of foreign STEM talent: short-term visitors to the United States with STEM backgrounds; foreign-born STEM workers; foreign post-doctoral fellows and visiting STEM researchers; foreign STEM doctoral students; and foreign students in U.S. bachelor's and master's programs. For each of these groups, we use our estimates of benefits and expected losses to generate net assessments of the benefits and losses associated with the presence of these groups in the United States.

2. Foreign STEM Talent in the United States

A. Introduction

In this chapter we first review the role of foreign STEM talent in the U.S. STEM workforce. We begin by defining the U.S. STEM workforce. We then define foreign STEM talent and present data on the participation of this talent in this workforce. We also assess the role of foreign STEM students among new entrants into this workforce. All the data presented here is from 2019 and earlier. Past trends in these data may not hold in the future. Several events that occurred in 2020, such as the COVID-19 pandemic and the signing of Presidential Proclamation 10043, may affect the future participation of foreign talent, especially foreign students, in the U.S. STEM workforce and educational system.

This chapter of the report draws from the Federal statistical data sources described briefly in Table A-1. The discussion in Table A-1 provides context on the population from which each source drew information. Where relevant, additional context about the data sources is provided when findings from that data source are discussed.

B. Definitions of the STEM Workforce

Several Federal and non-Federal entities have developed definitions of the STEM workforce. The definitions determine who is and who is not counted in the various sources of statistics on the U.S. STEM workforce. Each definition has been designed to suit specific statistical needs. Here, we summarize some of the key commonalities and differences in the definitions used. First, we highlight the distinction between STEM occupations and STEM degree fields. Next, we describe the distinctions between which disciplines are included in the different definitions of STEM (also sometimes called science and engineering [S&E]), STEM-related, and non-STEM occupations or degree fields). We provide a glossary of these terms at the end of the document.

1. Defining the Workforce Based on STEM Occupations and STEM Degrees

Statistical series on the STEM workforce generally use one of two definitions to characterize the workforce: (1) employment in STEM occupations or (2) individuals with STEM degrees. These two definitions tell us different things about the STEM workforce. Individuals in STEM occupations may or may not have STEM degrees, and individuals with STEM degrees may or may not work in STEM occupations, therefore we consider both groups here. Within this report, depending on the data source, we refer to either individuals in STEM occupations or individuals with STEM degrees.

By counting individuals in STEM occupations (also called STEM jobs), we learn how many people are working in roles that require STEM expertise. Individuals in STEM occupations do not necessarily have STEM degrees, although this is a common pathway into STEM jobs. For example, 20 percent of computer scientists do not have a degree in any STEM or STEM-related field of study (NSB/NSF 2021). Of all STEM workers (in "core" STEM jobs[1]), approximately 84 percent (in "core" STEM jobs) have a STEM bachelor's or advanced degree (Day and Martinez 2021).

Determining which jobs should be considered STEM jobs usually involves creating lists of occupations that are thought to require STEM expertise and skills. However, different organizations use slightly different definitions for what is a STEM occupation. For many years, based on the data sources used to study the STEM workforce (e.g., the National Survey of College Graduates), statements about the STEM workforce referred only to workers with bachelor's degrees or higher. Recently, more emphasis has been placed on trying to identify STEM occupations by the skills required, rather than degrees. The National Science Board (NSB) and others have been working to develop methods for counting and characterizing individuals in the "skilled technical workforce," who use STEM in their jobs, but do not have bachelor's degrees (NSB 2020).

By counting individuals with STEM degrees, we can learn how many STEM-trained individuals are in the U.S. workforce. Individuals with STEM degrees, however, do not all work in STEM occupations, as there are a large number of non-STEM occupations in which their analytical skills can be applied. In 2019, an analysis of the American Community Survey (ACS) found that only 28 percent of bachelor's or higher STEM-educated workers work in a STEM job (Day and Martinez 2021). There is a perceived value to having these STEM-trained individuals in the U.S. workforce, even if not in an occupation considered to be a STEM occupation.

2. Defining STEM, STEM-related, and Non-STEM Occupations or Degree Fields

Many criteria are used to determine whether an occupation or degree field is STEM, STEM-related, or non-STEM. These occupations and degree fields are sometimes also referred to as S&E, S&E-related, and non-S&E.[2] (We use STEM and S&E interchangeably in the remainder of this chapter.) Here, we highlight key similarities and differences among the definitions used by the data sources referenced.

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[1] "Core" STEM jobs include computer scientists, mathematicians, life and physical scientists, and engineers.

[2] S&E occupation or degree field is the term traditionally used by NSB/NSF to describe a STEM occupation or degree field. However, as of August 2021, NSB/NSF have begun to consider STEM workers more broadly than those in S&E and S&E-related occupations (NSB/NSF 2021). In this report, where we use S&E, it is because we used data that originated from NSB/NSF or NCSES sources that used this designation.

This chapter largely references data from Federal statistical sources, including the National Science Foundation's (NSF's) National Center for Science and Engineering Statistics (NCSES), the Census Bureau and the Department of Education's National Center for Education Statistics (NCES), and the Department of Labor's Bureau of Labor Statistics (BLS) (See Appendix A for more information about each of these data sources.) During data collection, occupations or degree fields are not classified as STEM, STEM-related, or non-STEM, but are often organized around standardized codes, such as the standard occupation classification (SOC) taxonomy for occupations or the classification of instructional programs (CIP) taxonomy for degree fields. When analyzing these data, researchers choose a particular definition for STEM, STEM-related, and non-STEM. For example, if we refer to the BLS definition of a STEM occupation, we are referring to the definition used for a particular BLS analysis with a citation to that analysis. Within a single Federal agency analysis, the lists of STEM, STEM-related, and non-STEM occupations or degree fields are always mutually exclusive, so if an occupation or degree field is included in the agency's definition of STEM, then it will not be included in its definition of STEM-related. Even within a single Federal agency, a single static definition of STEM, STEM-related, and non-STEM might not be used for every analysis.

All definitions include a "core" set of STEM occupations: computer scientists, mathematicians, biological, agricultural, and environmental life and physical scientists, and engineers. Social scientists, post-secondary STEM teachers, STEM managers, STEM technicians/technologists, and health fields are sometimes classified as STEM occupations and sometimes as STEM-related occupations. NSB/NSF and the Census Bureau always classify social scientists as STEM occupations, while BLS typically does not (NSB/NSF 2020; U.S. Census Bureau 2020a; BLS n.d. a). Health and medical occupations are considered STEM-related occupations by NSB/NSF and the Census Bureau, but BLS excludes them from its definition of STEM occupations. NSB/NSF considers health and medical science degree fields at the doctoral level to be STEM degree fields, rather than STEM-related, due to their focus on research (NSB 2020). One other important definition for STEM degree fields to keep in mind is the Department of Homeland Security (DHS) STEM Designated Degree Program list, which it uses to determine which degree fields qualify for the STEM Optional Practical Training (OPT) Extension (DHS n.d.). The DHS definition is among the broadest, as it encompasses nearly all degree fields that the other definitions consider STEM and STEM-related.

Throughout this report, most of the analysis we present uses the definition of a STEM or S&E workforce traditionally used by the NSB/NSF that includes individuals with a bachelor's degree working in S&E occupations. Table 1 lists the occupations that are considered to be in S&E, as well as the occupations considered to be S&E-related and non-S&E occupations based on the traditional NSB/NSF definitions for these terms (NSB/NSF

2021). When an alternate definition is used in this report, we make note of that difference in the text.

Table 1. NSB/NSF Definitions of S&E Occupations

Broad Occupation Categories	Occupations Included
S&E occupations	Computer and mathematical scientists; biological, agricultural, and environmental life scientists; physical scientists; social scientists and engineers; post-secondary S&E teachers
S&E-related occupations	Health and medical occupations; S&E managers (including health); Pre-college S&E teachers; S&E technicians and technologists
Non-S&E occupations	Non-S&E managers; Precollege or Postsecondary non-S&E teachers; Sales and marketing occupations; Social service and related occupations; Arts, humanities and related occupations

C. What Role Does Foreign Talent Play in the U.S. STEM Workforce?

1. Defining Foreign Talent

Some of our data sources report on "foreign" and "foreign-born" individuals differently. Data on the foreign-born U.S. workforce refer to individuals who are born outside the United States; they do not make distinctions on citizenship status. Statistics collected by the NSF report on individuals who have graduated from U.S. universities while simultaneously holding non-immigrant visas—excluding "foreign" individuals that began their university education on an immigrant visa or that transitioned to an immigrant visa during their education. We consider data sources using these somewhat varying definitions of "foreign" to be reasonable proxies for assessing the values associated with our individuals of concern.

The term *foreign talent* can be interpreted in several ways and as such is an imprecise term. Many reports refer to *foreign-born individuals*, many of whom are citizens of foreign nations, but a share of whom may be naturalized U.S. citizens or permanent residents. Other reports refer to *non-U.S. citizens* (sometimes called foreign nationals), which implies that those individuals have foreign citizenship, but does not necessarily mean that they are foreign born, nor does it indicate whether they are permanent or temporary residents of the United States. Some reports refer specifically to individuals who are temporary visa holders and permanent residents (i.e., they are not naturalized U.S. citizens). A glossary of these and other related terms can be found at the end of the document. We take care to be explicit about which groups we are describing throughout this document to reduce confusion and clarify for the reader whether statistics are directly comparable.

2. Foreign Talent and U.S. Immigration Policy

Current U.S. visa policies play a major role in determining the shares of foreign-born individuals in various occupation or degree categories. For example, the reason foreign-born computer scientists have one of the highest shares of foreign-born workers in an occupation is tied to the fact that those workers receive the largest share of H-1B visas, a common temporary visa type with which employers sponsor foreign workers with special skills to work in the United States (USCIS 2018). The reason the share of foreign-born workers in STEM jobs is higher for those with master's and doctoral degrees than for those with bachelor's degrees is tied to the fact that although there is a 65,000 cap on the number of H-1B visas awarded each year, an additional 20,000 H-1B visas are awarded to individuals with advanced degrees (USCIS 2021).

3. How Large Is the U.S. STEM Workforce?

Many Federal statistical sources and definitions of STEM can be used to estimate the size of the U.S. STEM workforce. Here, we describe data from one authoritative source on the size of the STEM workforce: the U.S. Census Bureau's ACS. Using data from the 2019 ACS, the NSB/NSF estimates U.S. companies employed ~8.6 million STEM workers in the United States in 2019,[3] meaning roughly 5.5 percent of all U.S. workers were employed in STEM occupations in that year (U.S. Census Bureau 2020; NSB/NSF 2021).[4] Approximately 6.6 million of these STEM workers had a bachelor's degree or higher (NSB/NSF 2021).

4. What Share of Individuals in STEM Occupations Are Foreign Born?

There are several estimates of the share of foreign-born workers in the U.S. STEM workforce. They vary depending on how the workforce is defined and which data sources are used. Using data from several sources, the NSB/NSF's *Science and Engineering Indicators: Science and Engineering Labor Force 2019* report details the share of foreign-born workers in S&E occupations by degree level in 1993, 2002, 2013, and 2017 (Table 2). As shown in the table, depending on whether the Scientists and Engineers Statistical

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[3] Using data from an alternate source, such as BLS's 2019 Occupational Employment and Wage Statistics (OEWS) program, we find an estimated ~9.3 million STEM workers. OEWS does not include social scientists and related occupations in its count and does not include self-employed individuals, as it is a survey of business establishments that pay unemployment insurance.

[4] NSB/NSF recently (August 2021) published an analysis of the U.S. STEM workforce using a new expanded definition that is broader than this traditional definition. The new expanded definition includes individuals without bachelor's degrees and those in middle-skill occupations associated with the skilled technical workforce. Based on the new expanded definition of the STEM workforce and ACS 2019 data, they find that there are approximately 36 million STEM workers in the United States, which means the STEM workforce constitutes 23 percent of the total U.S. workforce (NSB/NSF 2021).

Data System (SESTAT),[5] the ACS, or the National Survey of College Graduates (NSCG) is used, calculations yield slightly different estimates for the share of foreign-born workers in STEM occupations.

There are two clear trends in the 1993–2017 data on foreign-born individuals in the U.S. STEM workforce. First, the share of foreign-born workers in S&E occupations at all levels of education has steadily increased (Table 2). In 2019, 29 percent of college-educated STEM workers were foreign born, according to analysis of ACS data (Day and Martinez 2021). Second, the proportion of foreign-born individuals in S&E occupations increases with degree level. In 2017, foreign-born individuals comprised approximately 44 percent of all doctoral-level workers, 39 percent of master's-level workers, and 21 percent of bachelor's-level workers in S&E occupations. A different analysis of this data showed that of individuals in STEM occupations, more foreign-born workers have a doctorate (17 percent) than native-born workers (9 percent) (NSB/NSF 2019).

Table 2. Share of Foreign-born Workers in S&E Occupations, by Education Level in 1993, 2003, 2013, and 2017

	1993	2003		2013		2017	
Education	SESTAT	SESTAT	ACS	NSCG	ACS	NSCG	ACS
All college educated	15.8	22.6	25.1	26.5	27.7	29.5	29.1
Bachelor's	11.4	16.4	18.2	18.9	19.8	21.6	21.1
Master's	20.7	29.4	30.7	34.3	37.1	39.2	39.4
Doctorate‡	26.8	36.4	38.3	41.4	43.6	43.1	44.7

Source: Table reproduced from Table 3-21 NSB/NSF 2019.

‡ In these datasets, doctorate includes not only PhDs, but also EdD, ScD.

In parallel, we calculated our own estimates of the share of foreign-born individuals in the U.S. STEM workforce based on statistics from BLS on the number of employed foreign- and native-born individuals in the United States by occupational category (BLS 2019). We calculated the share of foreign-born employees in the categories of computers and mathematics; architecture and engineering; and life, physical, and social science. The average, weighted by the share employed, was 28.1 percent in 2018 (BLS 2019). This compares to figures of 29.5 percent from the NSCG and 29.1 percent from the ACS (Table 2).

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[5] SESTAT is an integrated data system from NCSES that includes data from NSCG, the Survey of Doctoral Recipients (SDR), and the now discontinued National Survey of Recent College Graduates.

The share of foreign-born workers varies across S&E occupations. In 2017, for occupations such as (1) computer and mathematical scientists and (2) engineers, more than half of workers were foreign born at 58.7 percent and 56 percent, respectively (Table 3). A total of 48.4 percent of biological, agricultural, and environmental life scientists; 39.6 percent of physical and related scientists; and 20.4 percent of social and related scientists were foreign born in 2017 (Table 3). For bachelor's-level workers, the occupational category with the highest share of foreign-born workers is physical and related scientists, followed by computer and mathematical scientists; engineers; biological, agricultural, and environmental life scientists; and social and related scientists (Table 3).

Table 3. Share of Workers in S&E Occupations Who Are Foreign Born, by Highest Degree Level and Broad S&E Occupational Category in 2017

Occupation	Bachelor's	Master's	Doctorate‡
Computer and mathematical scientists	24.3	48.6	58.7
Engineers	17.3	37.0	56.0
Biological, agricultural, and environmental life scientists	16.5	30.9	48.4
Physical and related scientists	27.4	23.5	39.6
Social and related scientists	12.8	13.6	20.4

Source: Table reproduced from NSB/NSF 2019 Figure 3-24.

‡ In these datasets, doctorate includes not only PhDs, but also EdD, ScD.

5. Doctoral-level Workers in STEM Occupations

Of roughly 2.5 million doctorate holders (in any field)[6] in the United States, approximately 2.1 million were employed in 2019 (Table 4). Of these approximately 2.1 million employed doctorate holders, around 44 percent were in S&E occupations. For unemployed doctorate holders or doctorate holders not in the labor force,[7] approximately 47 percent and 36 percent respectively had an S&E occupation as their last job.

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[6] Includes PhD holders in all degree fields, not exclusively in STEM degree fields.

[7] See glossary B for definitions of the meaning of "unemployed" and "not in the labor force."

Table 4. Number of Doctorate Holders in S&E, S&E-related, and Non-S&E Occupations by Labor Force Status in 2019

	Doctorate Holders	Employed Doctorate Holders	Unemployed Doctorate Holders	Doctorate Holders Not in Labor Force
S&E occupations	1,098,333	937,889	19,946	140,498
S&E-related occupations	453,721	386,896	4,039	62,786
Non-S&E occupations	963,722	765,116	14,928	183,678
Total	**2,521,580**	**2,089,901**	**42,639**	**389,040**

Source: STPI calculation using SESTAT based on NCSG public 2019 data. Numbers shown here represented the weighted data based on the demographics of the sample population.

Notes: These groupings of S&E and S&E-related occupations refer to the categories of occupations listed in the Glossary at the end of this document.

Labor force status indicates whether the respondent was employed, unemployed, or not in the labor force during the reference week of the NSCG. For employed individuals, the data in this table refer to their current occupation. For unemployed individuals and those not in the labor force, these data refer to their last occupation.

We can use these data to determine how many employed doctorate holders in S&E occupations were foreign born and how many were born in the top two countries of origin, China and India. Of the roughly 938,000 employed doctorate holders in S&E occupations in 2019, roughly 45 percent were foreign born (Table 5). Of all employed doctorate holders in S&E occupations in the United States in 2019, 11.1 percent were born in China and 6.7 percent in India.

Table 5. Number and Share of Employed Doctorate Holders in S&E Occupations in the United States by Place of Birth

	Number of Employed Doctorate Holders in S&E Occupations	Share of Employed Doctorate Holders in S&E Occupations
Total (U.S. born and non-U.S. born)	937,889	
Non-U.S. born	420,011	44.8%
Of which:		
China	104,190	11.1%
India	62,573	6.7%

Source: STPI calculation using SESTAT based on NCSG public 2019 data. Numbers shown here represented the weighted data based on the demographics of the sample population.

6. Current and Past Visa Status of Foreign-born Doctorate Holders in S&E Occupations

Because understanding the extent to which foreign-born doctorate holders come to the United States and stay is of interest to understanding their role in the STEM workforce, we considered their current citizenship status and the visa status with which they originally entered the United States. Of all doctorate holders born outside of the United States and employed in the United States in 2019, roughly half were naturalized U.S. citizens, and a quarter U.S. permanent residents (Table 6). For foreign-born doctorate holders employed in S&E occupations, 45 percent were naturalized U.S. citizens; 28 percent, U.S. permanent residents; 23 percent, temporary residents; and 4 percent U.S. citizens by birth.[8] Of foreign-born doctorate holders employed in S&E occupations in the United States, 45 percent were naturalized U.S. citizens (the remaining 55 percent were temporary residents or green card holders). Of foreign-born doctorate holders employed in S&E-related occupations or non-S&E occupations in the United States, a higher share are naturalized citizens at 57 percent and 63 percent, respectively.

Table 6. Share of Foreign-born, Employed Doctorate Holders in S&E, S&E-related, and Non-S&E Occupations by Current Citizenship Status

	Share of foreign-born U.S. citizens by birth	Share of foreign-born, naturalized U.S. citizens	Share of foreign-born, permanent residents	Share of foreign-born, temporary residents
Total	4%	54%	25%	17%
S&E occupations	4%	45%	28%	23%
S&E-related occupations	1%	57%	29%	13%
Non-S&E occupations	8%	63%	21%	8%

Source: STPI calculation using SESTAT based on NCSG public 2019 data. Numbers shown here represent the weighted data based on the demographics of the sample population.

Note: Individuals classified as foreign-born U.S. citizens by birth are likely individuals who were born outside of the United States, but who had at least one parent who was a U.S. citizen.

For all occupation types, foreign-born employed doctorate holders were most likely to have first arrived to the United States on a temporary resident visa issued for study or training (e.g., F-1, J-1, H-3) (Table 7). The share of foreign-born doctorate holders that first arrived on a visa for study or training was highest for those employed in S&E occupations (71 percent). For the remainder of foreign-born doctorate holders employed in

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[8] Individuals classified as foreign-born, native U.S. citizens are likely individuals who were born outside of the United States and who has at least one parent who is a U.S. citizen.

S&E occupations, 8.5 percent arrived on a U.S. permanent resident visa, 8.6 percent arrived on a visa for temporary work (e.g., H-1B, L-1A, L-1B), 5.1 percent arrived on a visa as the dependent of another person (e.g., F-2, H-4, J-2, K-2, L-2) and 2.9 percent arrived on an "other" temporary resident visa. The reason most foreign-born doctorate holders arrive on visas for study or training and not other entry visas is tied to current U.S. visa policies and the relative ease or challenge of successfully gaining entry into the United States using different visa types.

Table 7. Shares of Foreign-born, Employed Doctorate Holders in S&E, S&E-related, and Non-S&E Occupations by Visa Type upon Initial Entry into the United States in 2019

	Share of permanent U.S. resident visa	Share of temporary resident visa or temporary work visa	Share of temporary resident visa for study or training	Share of temporary resident as dependent	Share of other temporary visa	Share of U.S. citizens by birth
Total	12%	10%	62%	7%	5%	4%
S&E occupations	8%	9%	71%	5%	3%	4%
S&E-related occupations	11%	14%	60%	9%	5%	1%
Non-S&E occupations	15%	10%	51%	6%	10%	8%

Source: STPI calculation using SESTAT based on NCSG public 2019 data. Numbers shown here represent weighted data based on the demographics of the sample population.

Notes: Temporary resident visa or temporary work visas include H-1B, L-1A, L-1B, etc. Temporary resident visas for study or training include F-1, J-1, H-3, etc. Temporary resident visas as a dependent of another person include F-2, H-4, J-2, K-2, L-2, etc. Foreign born, native U.S. citizens do not require an entry visa; however, they are included in this table to account for 100% of foreign-born employed doctorate holders.

D. What Is the Role of Non-U.S. Citizens as New Entrants into the U.S. Doctorate STEM Workforce?[9]

1. What Share of U.S. STEM Doctorate Recipients Are Not U.S. Citizens?

Foreign talent plays a large role in the U.S. STEM workforce, particularly at the doctorate level. According to the NSCG,[10] many individuals with S&E doctorates in the U.S. workforce (around 88 percent) earned their doctorates in the United States (Okrent

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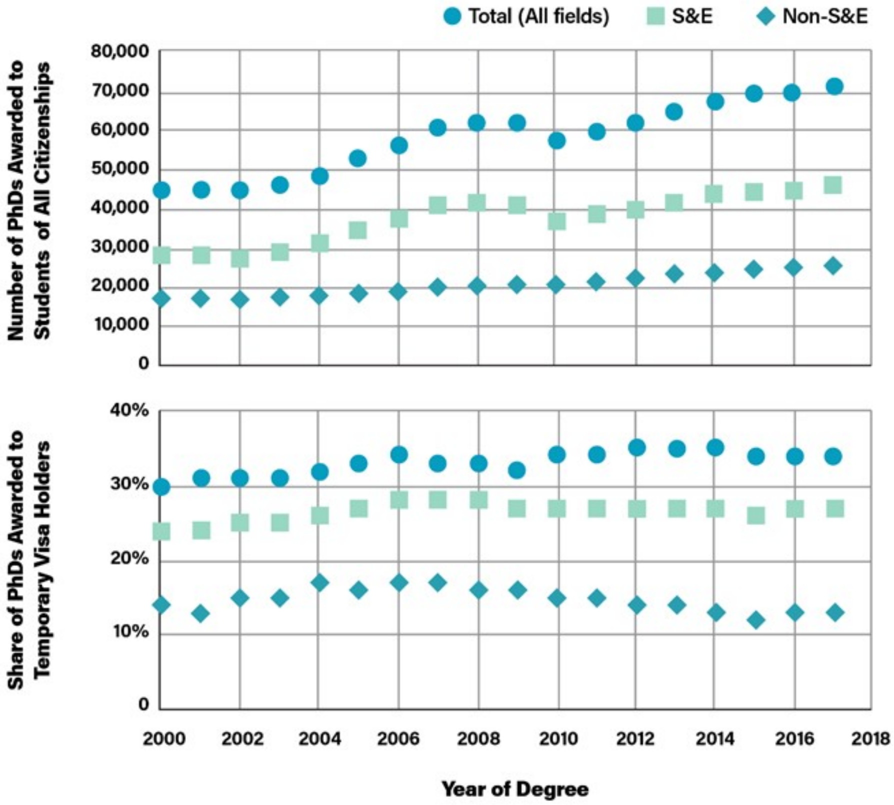
[9] All the data in this document are from 2019 or earlier, and therefore do not capture any of the effects of the COVID-19 pandemic on foreign student enrollment in U.S. institutions of higher education nor the effects of Presidential Proclamation 10043 prohibiting entry of some Chinese nationals from study of some STEM fields at U.S. institutions of higher education.

[10] The NSCG, unlike the SED and the SDR, includes U.S. employment information on college graduates who received their degrees outside of the United States.

and Burke 2021). In light of the importance of graduates from U.S. doctorate programs in the population of U.S. STEM workers with doctorates, in this section we present information on the number and share of S&E doctorates awarded by U.S. institutions to non-U.S. citizens over time, the top countries of origin for S&E doctorates, and the number and share of doctorates awarded to all non-U.S. citizens, and specifically from China, by broad field of study. Individuals who received doctorates from U.S. institutions of higher education are sometimes referred to as U.S. doctorates.

Figure 1 shows the number of S&E and non-S&E doctoral degrees awarded by U.S. institutions between 2000 and 2017. These data come from the NCES IPEDS completions survey, although we use the designations for S&E and non-S&E fields from NCSES (NSB/NSF 2019a). The number of S&E doctorates awarded annually in the United States has increased from 27,862 in 2000 to 45,729 in 2017, a 64 percent increase over that 17-year period. The share of S&E doctorates awarded to temporary visa holders has increased by 84 percent over the same time period; temporary visa holders made up 34 percent of all S&E doctoral degree awards in 2017.



Source: NSB/NSF 2019a. Table S2-11. Data from NCES IPEDS-C and NCSES Integrated Data System.

Note: All citizenships include U.S. citizens, permanent residents, and temporary visa holders.

Figure 1. Annual Numbers of Total (all fields), S&E and Non-S&E Doctoral Degrees Awarded by U.S. Institutions by U.S. Citizenship Status from 2000–2017

2. Countries of Origin for U.S. STEM Doctorate Recipients – Focus on China

Table 8 provides a summary of the number of non-U.S. citizens[11] who received S&E doctoral degrees at U.S. institutions from 2000 through 2017 for the top eight countries from where they originated. These data come from the NCSES Survey of Earned Doctorates (SED), a census of all research-based doctoral graduates from U.S. institutions of higher education (NSB/NSF 2019a). S&E doctorates were awarded to students from 212 regions, countries, or economies outside the United States between 2000 and 2017. Between 2000 and 2017, 210,053 S&E doctorates from U.S. institutions were awarded to non-U.S. citizens, of which 66,690 were awarded to students from China. Chinese nationals comprised 32 percent of all non-U.S. citizen S&E doctoral awards from U.S. institutions, the highest of any other country. The other top seven countries of origin were India (14 percent), South Korea (9 percent), Taiwan (4 percent), Canada (3 percent), Turkey (3 percent), Thailand (2 percent), and Iran (2 percent).

Table 8. S&E Doctoral Degrees Awarded by U.S. Institutions to Non-U.S. Citizens[a] by Country of Origin, Total from 2000 to 2017

	Doctorates awarded in all S&E fields (number)	Share of S&E doctorates awarded to non-U.S. citizens by student's country of origin
All regions, countries, or economies of origin[b]	210,053	
China[c]	66,690	32%
India	29,050	14%
South Korea	18,160	9%
Taiwan	9,127	4%
Canada	5,765	3%
Turkey	6,629	3%
Thailand	4,261	2%
Iran	4,345	2%

Source: Adapted from NSB/NSF 2019a. Table 2-4. Data from NCSES SED.

Notes:

a Data include temporary residents and non-U.S. citizens with unknown visa status.

b This entry includes 212 regions, countries, or economies, but excludes individuals with unknown region, country, or economy of origin.

c China includes Hong Kong.

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[11] Non-U.S. citizens here includes temporary residents and non-U.S. citizens with unknown visa status.

Table 9 summarizes the number and shares of doctorates awarded by U.S. institutions to all students, all foreign students, and students from China across S&E fields from 2000 to 2017. The data on the number of all doctorates awarded are from the NCES IPEDS completions survey, while the data on the number of doctorates awarded to Chinese nationals are from the NCSES SED, meaning the taxonomies of degree fields may not align precisely (NCSES 2020).

Between 2000 and 2017, 7 percent of doctorates at U.S. institutions in all degree fields went to Chinese nationals (Table 9). Of S&E doctorates awarded by U.S. institutions between 2000 and 2017, 10 percent went to Chinese nationals, compared to only 1 percent of non-S&E doctorates awarded between 2000 and 2017. Across the S&E fields shown here, computer sciences and mathematics had the highest shares of doctorates going to Chinese nationals at 19 percent each, but these fields also had among the lowest number of degrees awarded over this time span. For engineering, the field with the highest numbers of degrees awarded, 17 percent of doctorates went to Chinese nationals. The degree fields in order of decreasing share of doctorates awarded to Chinese nationals are: computer sciences (19 percent), mathematics (19 percent), physical sciences (14 percent), biological sciences (10 percent), social sciences (5 percent), and medical and other health sciences (2 percent). This is similar to the order of degree fields of doctorates awarded to all non-U.S. citizens: computer sciences (53 percent), engineering (51 percent), mathematics (46 percent), physical sciences (38 percent), social sciences (30 percent), biological sciences (28 percent), non-S&E (10 percent), and medical and other health sciences (8 percent).

Table 9. Number and Share of Doctorate Awards from U.S. Institutions by Country of Origin and by Field of Study from 2000 to 2017

	All (U.S. and foreign)	All foreign countries of origin	Share of all from foreign countries of origin	China[b]	Share of all from China
All fields	1,044,564	246,126	23.6%	71,864	7.0%
All S&E fields	674,549	210,053	31.1%	66,690	10.0%
Computer sciences	25,803	13,785	53.4%	4,962	19.0%
Mathematics[a]	25,938	11,889	45.8%	4,874	19.0%
Engineering	141,493	72,416	51.2%	24,714	17.0%
Physical sciences	75,556	28,671	37.9%	10,923	14.0%
Biological sciences	121,322	34,142	28.1%	11,879	10.0%
Social sciences	80,696	24,596	30.5%	3,877	5.0%
Medical and other health sciences	93,338	7,750	8.3%	1,492	2.0%

	All (U.S. and foreign)	All foreign countries of origin	Share of all from foreign countries of origin	China[b]	Share of all from China
Non-S&E	370,015	36,073	9.7%	5,174	1.0%

Source for all (U.S. and foreign) column from NSB/NSF 2019a Table S2-10. Data from NCES IPEDS-C.

Source for all foreign countries of origin and China columns adapted from NSB/NSF 2019a Table 2-4. Data from NCSES SED.

[a] Because NCSES SED and NCES IPEDS use different taxonomies for degree fields, the bounds of each degree field may differ slightly across the all (U.S. and foreign) and all foreign countries of origin/China data. As one example, the NCES IPEDS data on all (U.S. and foreign) mathematics doctorates includes statistics, while the NCSES SED data on all foreign countries of origin/China may only refer to mathematics and not statistics.

[b] China includes Hong Kong.

3. Do Non-U.S. Citizens with U.S. STEM Doctorates Stay in the United States Post-graduation?

To assess the importance of foreign students earning S&E doctorates at U.S. institutions as new entrants into the U.S. STEM doctorate workforce, we need to know how many stay in the United States post-graduation and what kind of work they do if they stay. In this section, we include information on both intentions to stay and actual stay rates for foreign STEM doctorate recipients and selected information on the sectors and occupations in which foreign STEM doctorates work. The distribution of these data are driven in great part by U.S. immigration policies, which dictate the visa options available to non-U.S. citizens students following graduation, and how challenging or competitive it may be for them to stay.

The two primary sources of information on stay rates of doctoral recipients are the SED and SDR. The SED, which is a census of all doctoral graduates from U.S. institutions of higher education, asks graduates at their time of graduation to indicate whether they intend to stay in the United States. This information on the intentions of non-U.S. citizen S&E doctoral graduates to stay in the United States is used to estimate an expected stay rate. Intention to stay does not indicate definite employment plans in the United States.

The expected stay rate for all temporary visa holder recipients of doctorates who graduated from U.S. institutions between 2014 and 2017 was about 77 percent (Table 10). For temporary visa holder recipients of doctorates who graduated from U.S. institutions between 2014 and 2017 from China and India, the expected stay rates were higher: 83 percent and 87 percent, respectively. Of the S&E recipients of doctorates who were temporary visa holders at graduation and planned to stay in the United States in the year after graduation, the majority (87 percent) were still in the United States 1 year post-graduation (Okrent and Burke 2021).

Table 10. Percentage of S&E Doctorate Recipients with Temporary Visas Planning to Stay in the United States after Graduation by Citizenship and Years of Graduation

	2006–09	2010–13	2014–17
All temporary visa holders	77.3%	74.9%	76.5%
China[a]	89%	84.1%	83.2%
India	88.6%	86%	87.6%

Source: NSB/NSF 2019.Table S3-24. Data from SED.

[a] Includes Hong Kong.

Because the SED is an annual census of all doctoral graduates from U.S. institutions with a 92 percent response rate, these data on expected stay can be calculated with high fidelity and on an annual basis, unlike the actual stay rates that can only be calculated from the SDR longitudinal data, which tracks a sample of approximately 10 percent of science, engineering, and health (SEH) doctoral graduates (selected from the SED) over time. The SDR surveys this sample of SEH graduates biennially. New doctoral graduates are added to the panel in each cycle while prior respondents continue to be surveyed until they are no longer eligible.

Using data from the SDR, we can estimate what share of S&E doctoral students with temporary visa status at the time of graduation[12] are still in the United States 5 or 10 years post-graduation. Five years after graduation, an estimated 71 percent of temporary visa holders who received their S&E doctorate in 2011–2013 were still in the United States; 10 years after graduation, an estimated 72 percent of those who graduated in 2006–2008 were still in the United States (Table 11). In other words, the 5-year stay rate was 71 percent and 10-year stay rate was 72 percent.

These stay rates are not uniform across all countries of origin nor across all degree fields. In Table 11, we highlight the 5- and 10-year stay rates for S&E doctoral students who are Chinese or Indian citizens and were temporary visa holders at the time of graduation. Stay rates for both groups were higher than the stay rates for all countries. For students from China, 83 percent remained in the United States 5 years following graduation and 90 percent remained in the United States 10 years following graduation. For students from India, 83 percent remained after both 5 and 10 years.

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[12] Some foreign-born or foreign citizen students are not temporary visa holders at the time of graduation. See Table 16.

Table 11. Temporary Visa Holders Receiving S&E Doctorates from U.S. Institutions in 2011–13 and 2006–08 Who Were in the United States in 2017, by Country of Citizenship at Time of Degree

	2011–13 foreign doctorate recipients	5-year stay rate	2006–08 foreign doctorate recipients	10-year stay rate
All temporary visa holders	39,250	71%	38,000	72%
China (including Hong Kong)	11,000	83%	13,000	90%
India	7,700	83%	6,450	83%

Source: NSB/NSF 2019. Table 3-22. Data from SDR.

Table 12 shows the stay rates for S&E recipients of doctorates who had temporary visa status at graduation from all countries of origin by degree field. The 5- and 10-year stay rates are similar across many fields, though are slightly higher for students with doctorates in computer and mathematical sciences and engineering and lowest for students with doctorates in social sciences.

Table 12. Temporary Visa Holders Receiving S&E Doctorates from U.S. Institutions in 2011–13 and 2006–08 Who Were in the United States in 2017 by S&E Degree Field

Degree field	2011–13 foreign doctorate recipients	5-year stay rate	2006–08 foreign doctorate recipients	10-year stay rate
Total	39,250	71%	38,000	72%
Biological, agricultural, health, and environmental life sciences	9,250	74%	9,400	73%
Computer and mathematical sciences	5,400	78%	5,100	75%
Physical sciences	6,150	67%	6,400	71%
Social sciences	4,900	52%	4,100	47%
Engineering	13,500	75%	13,000	77%

Source: NSB/NSF 2019a. Table 3-23. Data from SDR.

Note: Numbers may not add due to rounding.

4. What Do the Non-U.S. Citizen STEM Doctorate Recipients Who Stay in the United States Do?

A recent NSB/NSF report on the STEM labor force in the United States endeavored to find whether a cohort of U.S. S&E doctorate recipients on temporary visas at time of graduation who graduated between 2008 and 2017 were still working in an S&E

occupation, and whether that occupation was in the same field as their major doctoral degree field (NSB/NSF 2021). Temporary visa holders with doctorates in computer and mathematical sciences had the highest share of individuals working in an S&E occupation in their major degree field at about 87 percent. Those with doctorates in the physical sciences had the lowest share at about 47 percent (Table 13). These physical sciences doctorates, however, were nearly equally likely (about 40 percent) to be working in another S&E occupation outside of physical sciences. Temporary visa holders with doctorates in biological, agricultural, and health and environmental life sciences had the highest share of individuals working in an S&E-related occupation (about 15 percent), which includes medical and health-related occupations. Social science temporary visa holder doctorates had the highest share of individuals working in non-S&E occupations (about 19 percent).

Table 13. Employment Status in S&E Occupations in 2019 of S&E Recipients of Doctorates from U.S. Institutions on Temporary Visas at Graduation from 2008 to 2017 by Degree Field

Degree field	Working in S&E occupation that is in their major degree field	Working in S&E occupation that is not in their major degree field	Working in S&E-related occupation	Working in non-S&E occupation	Not working
Computer and mathematical sciences	87%	4%	2%	5%	2%
Biological, agricultural, and health and environmental life sciences	61%	13%	15%	7%	4%
Physical sciences	47%	40%	5%	4%	4%
Social sciences	63%	12%	2%	19%	4%
Engineering	61%	27%	5%	4%	3%

Source: NSB/NSF 2021. Figure LBR-35. Data from SED and SDR.

In a recent NCSES report, Okrent and Burke (2021) analyzed a cohort of S&E doctorate recipients from U.S. institutions who graduated between 2006 and 2015 and were living in the United States in 2017. The authors were specifically interested in a subset of individuals they term “early career stayers,” who were temporary visa holders at graduation and stayed in the United States for up to their first decade of post-doctoral employment. Table 14 shows the sectors of employment for “early career stayers” (who were temporary visa holders at the time of graduation) and individuals who were U.S. citizens or permanent residents at the time of graduation. The biggest differences between the employment of these two groups are in the for-profit business sector, and academic 4-year college or university and government sectors. Forty-six percent of “early career stayers” were employed at for-profit businesses compared to 27 percent of individuals that were U.S. citizens or permanent residents at graduation (Table 14); 24 percent of "early career stayers" were employed at academic 4-year colleges or universities compared to 31 percent of U.S. citizens or permanent residents. Four percent of "early career stayers" were employed in government compared to 11 percent of U.S. citizens or permanent residents.

The same publication by Okrent and Burke (2021) explored the citizenship status of S&E doctoral graduates from U.S. institutions who had temporary visa status at graduation. They looked at the citizenship status in 2017 of those individuals who graduated between 2006 and 2015 and were living in the United States in 2017. They found that 52 percent of these "early career stayers" had become U.S. citizens by 2017, while 15 percent were permanent residents and 33 percent were temporary residents (Table 15). At the time of graduation, 71 percent of foreign-born SEH doctorate recipients were temporary visa holders, nearly 12 percent were permanent residents, and approximately 12 percent were U.S. citizens, native or naturalized (Tables 16). In another published analysis of stay rate data, Finn et al. showed that after 5 to 7 years the percentage of temporary residents attaining U.S. citizenship begins to sharply increase, with roughly 30 percent of temporary residents ultimately attaining U.S. citizenship within 12 years of graduation (Finn and Pennington 2018).

Table 14. Sector of U.S. Employment for S&E Doctorate Recipients from U.S. Institutions Living in the United States in 2017 By Citizenship Status at Time of Graduation (2006–2015)

Sector	Share of all temporary visa holders ("early career stayers") at graduation	Share of all U.S. citizen or permanent residents at graduation
Business private	46%	27%
Business nonprofit	6%	8%
Business other	6%	6%
Academic 4-year college or university	24%	31%
Academic other	14%	14%
Academic 2-year and pre-college	1%	4%
Government	4%	11%

STPI calculation based on Figure 5 from Okrent and Burke 2021. Data from SED and SDR.

Table 15. Citizenship Status of U.S. S&E Doctorate Holders Who Graduated between 2006 and 2015 and Had Temporary Visa Status at Graduation and Were Still Living in the United States in 2017

Citizenship status in 2017	Percent
U.S. citizen	52%
Permanent resident	15%
Temporary visa holder	33%

Source: Okrent and Burke 2021. Figure 2. Data from SDR and SED.

Policymakers often ask whether the United States is retaining foreign talent at the same rate as in the past. For a number of reasons this question is challenging to answer. First, it is difficult to compare the 5- or 10-year stay rates over time because each cohort of graduating doctorates may have a different stay rate (Finn 2014). Sometimes drastic changes in stay rates are discussed in the context of geopolitical or economic events (e.g., Tiananmen Square). The time delay in which stay rate data are published can also make it challenging to study the trends. For example, the most recent stay rate data, published in September 2019 (with an update expected in a forthcoming *Science and Engineering Indicators 2022* report on "Higher Education in Science and Engineering") are based on the SDR from 2017 for doctorate recipients who graduated in 2011–2013 (for the 5-year stay rate calculation) and in 2006–2008 (for the 10-year stay rate calculation).

Table 16. Citizenship Status of Foreign-born SEH Doctorate Holders at Time of Graduation

Citizenship status at graduation	Percent
U.S. citizen, native	2.8%
U.S. citizen, naturalized	9.5%
Permanent resident	11.8%
Temporary visa holder	71.0%

Source: Based on STPI's calculations of the SDR 2019.

An alternate, though perhaps less repeatable, method using curriculum vitae or LinkedIn information has recently been used to estimate stay rates for recent doctoral graduates. Researchers from the Georgetown Center for Security and Emerging Technology (CSET) analyzed curriculum vitae and LinkedIn employment information for 1,999 doctorates who completed AI-related dissertations at U.S. universities from 2014 to 2019 (Zwetsloot et al. 2019). They found that among this group, more than 90 percent stayed in the United States initially and more than 80 percent were in the United States 5 years after graduation.

Challenges with measuring changes in stay rates aside, several published analyses have discussed possible reasons for decreasing stay rates. We briefly discuss a few potential reasons. Finn and Pennington (2018) reported that S&E recipients of doctorates who received foreign financial support during graduate school (as reported in the SED) had much lower stay rates than the average, closer to 20–25 percent for both the 5- and 10-year stay rates. The authors hypothesize that foreign financial support (if from their home country) could lead to closer ties to the home country. Based on STPI's analysis of SED data, the share of doctoral recipients receiving foreign support has increased over the past several years. In 2013, 3.6 percent of female doctorate recipients and 5.8 percent of male doctorate recipients received foreign support, while in 2019, 6.3 percent of female doctorate recipients and 8.5 percent of male doctorate recipients received foreign support.[13]

Kahn and MacGarvie (2020) studied whether delays in granting permanent residency visas affect stay rates of Chinese and Indian STEM doctoral graduates from U.S. institutions. In particular, they consider the rate at which employment-based EB-2 permanent residency visas are granted and how the limit to the number of EB-2 visas available per country have lengthened the wait time for Chinese and Indian applications to as long as 5 to 10 years. The authors conclude that "the stay rate of Chinese graduates declines by 2.1 percentage points for each year of delay, while Indian graduates facing delays of at least 5½ years have a stay rate that is 10.6 percentage points lower."

Han and Appelbaum (2016) and Han et al. (2015) identified several important factors that affect why foreign graduate students would want to stay in the United States after graduation: whether future career opportunities was among their initial reasons for coming to the United States for graduate study, their desired career path, whether their desired career path is research-oriented or not, perceptions of their advisor, and family, among others.

E. Findings

1. In 2019, there were ~8.6 million STEM workers in the United States, meaning roughly 5.5 percent of all U.S. workers were in STEM occupations.
2. Foreign-born workers account for a substantial share of the U.S. STEM workforce. In 2017, foreign-born individuals accounted for ~29 percent of college-educated workers in STEM occupations. For doctorate-educated individuals, foreign-born STEM workers comprise an even higher share of talent at ~44 percent.
3. In 2017, ~45,000 STEM doctorates were awarded by U.S. institutes of higher education. Approximately one-third of STEM doctorates were awarded to non-

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[13] The only reason we break this down by male and female PhD recipients is that the published data tables from the SED about sources of support for PhD recipients present this data by male and female PhD recipients.

U.S. citizens on temporary resident visas. In some fields, such as computer science and mathematics, over half of all graduating doctorates are non-U.S. citizens on temporary visas.

4. Approximately 77 percent of these non-U.S. citizen doctorate recipients on temporary resident visas intended to stay in the United States following graduation. Approximately 71 percent stay for at least 5 years and 72 percent stay for at least 10 years post-graduation. For doctorate recipients from China and India, their stay rates are higher, with a 5-year stay of 83 percent for both nations, and a 10-year stay rate of 90 percent for students from China and 83 percent for students from India.
5. These graduates represent a large pool of potential new entrants into the U.S. STEM workforce.

3. Economic Benefits of Foreign STEM Talent to the United States

This chapter provides estimates for four different economic benefits generated by foreign STEM talent in the United States:

1. Contributions to U.S. Gross Domestic Product (GDP) from labor value-added from foreign-born STEM talent employed in the United States;
2. Increases in U.S. GDP from foreign-born STEM talent's contributions to increases in total U.S. factor productivity (TFP);
3. Value-added generated by companies that foreign-born entrepreneurs have helped found in R&D-intensive industries; and
4. Contributions to U.S. GDP from payments by foreign nationals, including students and academics, for tuition, room and board, and other expenses associated with travel to the United States for educational and academic purposes.

A. Estimates of the Labor Contribution to U.S. GDP from Foreign STEM Talent

1. Introduction

GDP is measured three different ways. GDP by sector of origin is based on production. Under this approach, GDP equals the value of all the goods and services produced in a year minus the value of the intermediate goods and services needed to produce them, which is called intermediate consumption. This difference is also referred to as value-added. A second approach, GDP by end use, measures all the goods and services consumed or invested in the United States, netting out the value of goods and services imported from or exported to other countries. The third approach, GDP by factor incomes, measures the incomes (wages, salaries, and benefits; returns to capital; and rents) generated by all factors of production: labor; physical capital; and natural resources, often referred to as "land." In accordance with GDP accounting, all three measures are identical: the value-added generated by these factors equal their returns, which equals consumption and investment minus the balance of goods and services imported or exported from other countries. However, GDP estimates for each of these three measures differ due to problems in collecting the data used to measure them.

2. Approach

We use statistics on total employment of STEM workers in 2019 from two different data sources. We chose 2019 rather than 2020 for our analysis so as to avoid the disruptions to the U.S. labor market caused by the COVID pandemic. As discussed in Chapter 2, the BLS Occupational Employment and Wage Statistics (OEWS) program (BLS 2019a) is a survey of millions of U.S. businesses. One of the questions it asks pertains to the numbers and categories of employees of those businesses. OEWS defines STEM employees as scientists, technicians and other technologists, engineers, and mathematicians and computer scientists; it excludes health care workers, even those with medical degrees, but includes scientists and other researchers engaged in medical and biological research (BLS 2019a). In 2019, OEWS estimated that there were 9,345,230 STEM workers in the United States. This number includes part-time as well as full-time employees. This number includes only individuals who are paid a wage or salary; it does not include individuals who run unincorporated businesses that do not pay salaries or wages, such as self-employed consultants.

The second number on total employment of STEM workers is from "Table 1. STEM and STEM-Related Occupations by Sex and Median Earnings" from the 2019 ACS (U.S. Census Bureau 2020). As noted above, the ACS is a survey of 3.5 million households (BLS n.d.). The occupations listed for the two surveys are virtually identical with the exception of the inclusion of social scientists in the ACS. To make our estimates comparable, we subtracted out the social science category in the ACS for our analysis. After removing social scientists, according to the ACS, the number of STEM workers in the United States in 2019 was 10,414,400: 11.4 percent (1,069,170 workers) more than the OEWS number.

To estimate the contributions generated by foreign STEM talent to U.S. GDP, we first estimated the total labor value-added by U.S. STEM workers (i.e., the labor contribution of STEM workers) to U.S. GDP. To do so, we multiplied the total number of workers with STEM degrees by an estimate of their labor value-added based on average STEM worker compensation. In competitive labor markets, like those for STEM workers, compensation reflects that marginal revenue product of the workers, as companies will pay up to but no more than the additional revenue that the worker brings to the company. This marginal revenue product reflects the labor value-added generated by the worker.

Compensation consists of wages and salaries plus benefits. For our estimate of wages and salaries, we used the OEWS mean national salary for STEM workers, which was $95,350 in 2019 (BLS 2019a).[14] This compares to an average salary of $50,600 for non-STEM workers and an average salary for the entire labor force of $66,778 (BLS 2019).

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[14] We did not use salary information from the ACS because the ACS provides only median, not mean salaries.

The use of \$95,350 for foreign-born STEM workers assumed that they are paid the same as U.S. STEM workers. Evidence for this assumption is mixed. On the one hand, in 2019 median (not mean) salaries of naturalized science and naturalized engineering doctorates—a subset of total workers with STEM degrees—were 14.7 and 7.9 percent higher than for U.S.-born doctorates in these categories (NSF 2020).[15] On the other hand, in 2019, median salaries of non-citizen foreign-born science and engineering doctorates were 8.3 and 3.7 percent lower than those of U.S.-born U.S. doctorates (NSF 2020).[16] In addition, in 2019, median salaries of female STEM workers the United States were 15.9 percent less than median salaries of male STEM workers. The share of female STEM workers in total foreign-born STEM workers tends to be lower than the share of female STEM workers in total U.S.-born STEM workers, which would push average foreign-born STEM worker salaries up compared to average salaries of U.S.-born STEM workers, where the share of women is higher. Because of the lack of more detailed information about these offsetting trends, for the purposes of this estimate we assume that foreign-born workers with STEM degrees earn the same mean salary as all STEM workers in the United States.

We then estimated the average value of benefits for the entire STEM workforce. For this purpose, we used the average share of benefits to total compensation for civilian professional and related occupations in the United States from December 2019, which was 31.7 percent (BLS 2019b). We used this figure to generate an estimate of mean benefits of \$44,255 and total compensation for STEM talent of \$139,605. This figure for total compensation reflects that labor value-added provided by these individuals. We multiplied this number by the total number of STEM workers in the United States to estimate the total labor value-added generated by STEM worker labor. We then multiplied this estimate of labor contribution generated by all workers in the U.S. STEM workforce by 28.1 percent, our estimate of the share of foreign-born STEM workers in this total.

3. Results

Table 17 shows the results of our calculations. The mean value of labor value-added by each foreign-born STEM worker to U.S. GDP is \$139,605. Using this figure and the OEWS number for total STEM employment, we estimate the total labor value-added from STEM workers in 2019 was \$1,305 billion, 6.1 percent of total U.S. GDP in 2019. Labor value-added from foreign-born STEM workers was \$367 billion—28.1 percent of \$1,305

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[15] In 2019, U.S.-born science PhDs had a median salary of \$109,000, while naturalized science PhDs earned \$125,000, a difference of 14.7 percent. U.S.-born engineering PhDs had a median salary of \$139,000, while naturalized science PhDs earned a median salary of \$150,000, a difference of 7.9 percent (NSF 2020).

[16] Non-U.S. citizens with science PhDs, but employed in the United States, earned a median salary of \$100,000 while those with engineering PhDs earned \$120,000, differences of -8.3 and -3.7 percent, respectively, compared to the median salaries of U.S.-born PhDs (NSF 2020).

billion—or 1.7 percent of U.S. GDP in 2019. Using this same mean value for compensation and the ACS number for total STEM employment minus social scientists, we estimate the total labor value-added from STEM workers in 2019 was $1,454 billion, 6.8 percent of total U.S. GDP in 2019. Labor value-added from foreign-born STEM workers was $398 billion, or 1.9 percent of U.S. GDP in 2019.

Table 17. STPI Estimate of Labor Value-Added in U.S. GDP Generated by Foreign-born Workers with STEM Degrees in 2019

Source	Total STEM Workers[a]	Share of Foreign-born STEM Workers[b]	Estimate of Foreign-born STEM Workers	Mean STEM Worker Compensation[c]	Labor Value-Added from STEM Workers (billions of $'s)	Labor Value-Added from Foreign-Born STEM Workers (billions of $'s)
OEWS	9,345,230	28.1%	2,628,063	$139,605	$1,304.6	$366.9
ACS[d]	10,414,400	28.1%	2,928,734	$139,605	$1,453.9	$408.9

Sources: [a] BLS 2019a, [b] NSF 2020, [c] STPI calculation from BLS 2019a and BLS 2020, [d] U.S. Census Bureau 2020

B. Estimate of Increases in U.S. GDP from Foreign STEM Talent's Contributions to Innovation

1. Introduction

In this section, we estimate the contribution of foreign STEM talent in the United States to increases in U.S. GDP through its contributions to raising TFP. TFP is that part of growth in GDP that is unexplained by increases in labor or the capital stock.

The economist Robert Solow developed an economic growth model that posits output as a function of capital and labor and an exogenous factor that captures non-factor-specific productivity (Solow 1956):

$$Y = A_t \times f(K_t, L_t)$$

where Y is GDP; K, capital; L, labor: and A_t the productivity factor at time, t. The rate of change of A_t is the rate of growth in TFP.

Table 18 shows cumulative increases and average annual increases in U.S. GDP from 2000 to 2019 and the increase in GDP in 2019 in total and estimates of increases in GDP due to increases in labor, capital, and TFP over this time period.

2. Assumptions

We adopted the following assumptions to generate our estimates of increases in U.S. GDP from foreign STEM talent's contributions to U.S. innovation:

1. Innovation drives all increases in TFP;
2. U.S.-based STEM talent drives all innovation in the United States; and
3. The share of foreign STEM talent in the total U.S. STEM labor force is equal to its contribution to U.S. innovation, i.e., foreign-born and U.S.-born STEM workers are equally productive when it comes to innovation.

Table 18. Contributions of Labor, Capital, and TFP to Increments in U.S. GDP (Billion 2019 $'s)

	Total	Labor[a]	Capital	TFP
Cumulative increment to GDP 2000–2019	$7,276	$65	$4,246	$2,965
Average annual increment to GDP 2000–2019	$364	$3	$212	$148
Share of annual average increments to GDP 2000–2019	100.0%	0.9%	58.3%	40.8%
Increment to GDP in 2019	$453	$106	$193	$154
Average shares of labor and capital in GDP 2000–2019		63.1%	36.9%	
Shares of labor and capital in GDP in 2019		61.9%	38.1%	

Source: Calculated from BEA n.d. and BLS n.d. a.

Notes: TFP's contribution to GDP was calculated from increments in GDP in 2019 dollars from 2000 to 2019 and changes in TFP (BEA n.d.). Contributions of labor and capital to changes in GDP were calculated from changes in labor and capital inputs and shares of labor and capital in GDP normalized by the change in GDP not attributed to TFP.

[a] Because of the large declines in employment in 2008–2009, the incremental labor contribution to GDP in those years was negative. The sharp declines in those years resulted in the very low contributions of labor to GDP over the 20 years cumulatively and on average.

These assumptions set an upper bound on the contributions of domestic STEM talent to TFP. Increases in U.S. TFP are driven by innovations from outside the United States, not just domestic innovations. Consequently, the U.S. STEM workforce is not solely responsible for increases in U.S. TFP. Second, because TFP is a residual, it incorporates the effects of other factors, such as increased gains from trade. Ascribing all increases in TFP to innovation omits the effects of these other factors. However, for our purposes, we do not adjust for these upward biases.

3. Approach

To estimate the dollar value of increases in TFP due to foreign STEM talent's contribution to U.S. innovation, we first calculated annual increases in GDP in constant price dollars of 2019 (BLS n.d. a). We calculated these increases in GDP for each year from 2000 to 2019. We then used an index of TFP from the BLS to calculate how much of the increase in GDP was due to changes in TFP (BLS n.d. a).[17,18] We both summed and took the average of this series to generate the cumulative increase in GDP from 2000 to 2019 stemming from increases in TFP and the average annual increase. We assumed that these increases are entirely due to innovation. Following Romer (1990), we assume that innovation is the output of R&D and that R&D is driven entirely by STEM talent. Following the logic from the previous section, we assume that the share of increases in TFP that can be ascribed to foreign STEM talent is equal to the share of foreign-born talent in the U.S. STEM workforce, which, as noted above, we estimate is 28.1 percent (STPI calculations from BLS 2019). Appendix B shows the data and calculations we employed.

4. Results

Table 19 shows our results. As can be seen, improvements in TFP resulted in average annual increases in GDP of $148 billion 2019 dollars between 2000 and 2019, or an average annual contribution to GDP growth of 0.8 percentage points out of average annual growth of 1.9 percent per year over this period. In 2019, the increase was $154 billion. Using the figure of 28.1 percent of the U.S. STEM talent labor force as foreign born, we estimate foreign-born STEM talent contributed an average of $42 billion 2019 dollars annually to U.S. GDP through its contributions to U.S. innovation. These increases in GDP are driven solely by improvements in productivity, without them GDP growth would have been lower, limited to increases in the labor force and the capital stock.

Using the total number of STEM workers from the OEWS survey and the ACS, we estimate the foreign-born STEM workforce in the United States at 2.63 million to 2.93 million. In addition to these STEM workers, doctoral students also contribute to innovation through their research. We estimate foreign STEM doctoral students at 109,263. Using these numbers, on average, each foreign-born STEM worker and foreign doctoral student in the United States added from $13,724 to $15,232 to U.S. GDP from their contributions to increasing U.S. TFP. In the first year when the growth in productivity is realized—the numbers reported here—the additional output from the increase in RFP is likely to be captured by greater returns on capital. As labor markets adjust over time, STEM workers are likely to enjoy increased compensation tied to increases in demand for R&D and the increases in productivity due to STEM talent.

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[17] The BLS calls its index multifactor productivity. Multifactor productivity is used interchangeably with total factor productivity.

[18] We also calculated contributions of labor and capital to changes in GDP in 2019 dollars from indices of labor and capital inputs and shares of labor and capital in GDP (BLS n.d. a). We normalized these contributions of labor and capital by the change in GDP not attributed to TFP.

Table 19. STPI Estimates of Increases in U.S. GDP Driven by Improvements in U.S. TFP Generated by Foreign-born Workers with STEM Degrees (Billion of 2019 $'s)

STEM Workforce	Cumulative Increase in GDP Due to Increases in TFP (2000–2019)	Average Annual Increase in GDP Due to Increases in TFP (2000–2019)	Increase in GDP Due to Increases in TFP in 2019
Total	$2,965	$148	$154
Foreign born	$834	$42	$43
Per capita increases in GDP (OEWS)		$15,232	$15,812
Per capita increases in GDP (ACS)		$13,724	$14,247

Source: Calculated from BEA n.d. and BLS n.d. a.

C. Contributions of Companies Founded by Foreign-born Entrepreneurs and Their Chief Executive Officers to STEM-Intensive Sectors of the U.S. Economy

1. Introduction

Immigrants have long played an important role in founding leading corporations and creating new industries in the United States. As of 2018, 100 corporations on the Standard and Poor's (S&P) list of the 500 largest publicly traded corporations (S&P 500) were founded by individuals born outside the United States (New American Economy Research Fund 2018). In many instances, companies founded or managed by foreign STEM talent have commercialized important innovations in the United States. For example, Google founder Sergey Brin, former Intel CEO Andrew Grove, and SpaceX founder Elon Musk are foreign born. Companies that they have founded or for which they worked contribute to U.S. GDP through their output and employment.

There is substantial literature on the role of foreign-born entrepreneurs in creating high technology companies in the United States (e.g., Anderson 2018; Hart and Acs 2011; Wadhwa et al. 2012; Kerr and Kerr 2019). Hart and Acs (2011) found the share of foreign-born entrepreneurs in high-impact, high-technology companies was 16 percent. Another survey found that 24.3 percent of a sample of engineering and technology companies founded between 2005 and 2011 had at least one foreign-born founder (Wadhwa et al. 2012). A more recent study of foreign-born entrepreneurship found the percentage of high technology companies with a foreign-born founder was 20.0 percent in 2012 (Kerr and Kerr 2019). A study by Anderson (2018) found that 50 of 91 (55 percent) of relatively new privately held companies valued at $1 billion or more, often referred to as "unicorns," were founded by at least one foreign-born entrepreneur. In addition, in 75 of these 91 companies (82 percent) at least 1 foreign-born individual filled a key management or product development position, such as CEO, chief technology officer, or vice president of engineering (Anderson 2018). Nearly one-quarter (20 of 91) of these companies had a founder who first came to the United States as an international student. Job growth in these companies can be substantial. Many of the "unicorns" with at least one foreign-born founder doubled or substantially increased the number of employees at the company over the previous 2 years (Anderson 2018).

2. Approach

We provide rough estimates of the contribution of companies founded by foreign-born entrepreneurs to value-added from R&D-intensive industries in the United States. We draw upon the shares of foreign entrepreneurs in founding technology companies as reported above. We use 16 percent at the lower end (Hart and Acs 2011) and 24.3 percent at the upper end (Wadhwa et al. 2012). These percentages (16 to 24.3 percent) are above the share of the foreign born in the total U.S. population, which was 13.6 percent in 2019 (U.S. Bureau of the Census 2020). Because the total number of companies was so small, we did not use the 55 percent founders of "unicorns" who were foreign born in our estimates, although we found the findings of great interest (Anderson 2018).

We multiplied these percentages of companies with foreign-born founders by total value-added and value-added ascribed to the gross operating surplus, which we view as returns to capital, for a set of R&D-intensive industries to which these companies belong. We culled the industries from a table for gross output for all U.S. industries (BEA n.d. a). The list of industries is shown in Appendix C. We grouped these industries within the subsectors listed in bold in Appendix C. We then summed the output figures for each of industries by subsector and multiplied these sums by percentages of value-added and value-added attributed to gross operating surplus in total output from the table "Shares of Gross Output by Industry" (BEA n.d. b). We then summed value-added and value-added attributed to gross operating surplus across all the subsectors for these R&D-intensive industries. These sums were multiplied by the percentages of companies with foreign-born founders to generate estimates of the contributions of companies with foreign-born entrepreneurs to U.S. GDP.

3. Results

Table 20 shows our estimates. We underline that many factors go into generating value-added from R&D-intensive industries, not just the role of entrepreneurs, U.S. or foreign born. Consequently, we stress that these estimates are illustrative. Total value-added from our set of R&D-intensive industries in 2019 was $1,623 billion, 7.6 percent of GDP. The gross operating surplus, the capital returns component of value-added, was $721 billion, 3.4 percent of GDP. We estimate that the share of value-added to GDP generated by R&D-intensive industries that might be attributed to companies with foreign-born entrepreneurs ranges from $260 billion to $394 billion, 1.2 and 1.8 percent of 2019 GDP, respectively. The respective figures for gross operating surplus for the low and high parameters were $115 billion and $175 billion, or 0.5 and 0.8 percent of 2019 GDP, respectively.

Table 20. STPI Estimates of the Value-Added and Gross Operating Surpluses of R&D-Intensive Industries Generated by Companies Founded by Foreign-born Entrepreneurs in 2019

	Total	Foreign-Born Entrepreneurs Low	Foreign-Born Entrepreneurs High
Shares	100%	16%	24.3%
Gross output (billion $'s)	$2,783.2	$445.3	$676.3
Value-added (billion $'s)	$1,622.9	$259.7	$394.4
Value-added as a share of GDP	7.6%	1.2%	1.8%
Gross operating surplus (billion $'s)	$721.2	$115.4	$175.2
Gross operating surplus as a share of GDP	3.4%	0.5%	0.8%

Notes: Gross output and value-added of R&D-intensive industries calculated from BEA n.d. a and BEA n.d. b. Percentages of foreign-born entrepreneurs taken from Hart and Acs 2011 (low) and Wadhwa et al. 2012 (high).

D. Contributions of Tuition Payments to the U.S. Economy from Foreign STEM Students

1. Introduction

Foreign students have become an important part of the student body of many U.S. colleges and universities. They accounted for 4.2 percent of all undergraduate students (associate and 4-year colleges) and 10.2 percent of all graduate school enrollments in 2019 (IIE 2019; U.S. Census Bureau 2019). Almost half of all foreign students in undergraduate and graduate programs were enrolled in STEM fields (CRS 2019).

Expenditures by these students on tuition have become an important source of revenue for numerous programs in many universities (CRS 2019). Other expenditures by these students, such as living expenses, books, travel in the United States and to and from their home countries, also benefit the U.S. economy.

2. Approach

a. Foreign Transactions

The U.S. Government reports exports of education-related travel in U.S. international economic accounts (BEA 2021). These exports include expenditures on tuition, living expenses, and other expenditures related to education by students enrolled in primary, secondary, and post-secondary programs at educational institutions in the United States who are not U.S. citizens, immigrants, or refugees (BEA 2021). It also includes expenditures on dependents of students, like spouses and children, who accompany them to the United States. They do not include expenditures by travelers on education-related visas working in the United States after graduation under Optional Practical Training or similar programs. Foreign students' average expenditures, which are used for calculating exports, are based on data collected by SEVIS covering tuition, living expenses (including expenses for dependents), and other expenses (BEA 2021).

To calculate U.S. exports of educational services and travel related to education by foreign STEM talent and by Chinese STEM talent, we multiplied the reported statistics for by the share of STEM students among all foreign students and the share of Chinese STEM students among all foreign students.

b. Costs of Tuition and Room and Board

To measure U.S. revenues from foreign STEM students to the United States, we took a different approach to the numbers from U.S. export statistics. In 2018, 90.5 percent of foreign undergraduates and 62.1 percent of foreign graduate students paid for their education in the United States from family and other foreign sources (IIE 2020). Among graduate students, most foreign STEM doctoral students receive funding from the university in which they are enrolled (Feldgoise and Zwetsloot 2020; Kerr 2021); the majority of the 62.1 percent of foreign graduate students who pay for their studies from foreign sources tend to be enrolled in terminal master's degree programs.

To estimate the value of expenditures by foreign STEM students to the U.S. economy—and among these, students born in China—we obtained information on foreign STEM enrollments in undergraduate and graduate programs from Table 2.3 from *The State of U.S. Science and Engineering 2020* (NSF 2020). We obtained information on Chinese enrollments from Zwetsloot (2020). The NSF data report only on total STEM graduate enrollments. We applied the proportions between Chinese doctoral and master's degree students from Feldgoise and Zwetsloot (2020) to the total foreign STEM graduate student population to split the NSF numbers between master's degree and doctorate programs. We then multiplied these numbers by the cost of tuition and room and board for undergraduate and master's degree students from "Trends in College Pricing 2019" (College Board 2020). We used figures for tuition and room and board from private schools for our high estimates, and we used out-of-state tuition and room and board from public universities for our lower estimates. We did not include figures for doctoral students as we assume they are funded by the university that they attend.

3. Results

a. Balance of Payments

In 2018, foreign expenditures on travel to the United States for educational purposes ran $42.6 billion. Multiplying these numbers by the share of foreign STEM students in total foreign students (51.3 percent) yields $21.9 billion (Table 21). Multiplying these numbers by the share of Chinese STEM students in total foreign students (15.1 percent) yields $6.5 billion (Table 21).

Table 21. STPI Estimates of the Expenditures by All International and Chinese STEM Students on Educational Travel and Educational Services in the United States in 2018

	Total	STEM	Chinese STEM
Shares of total foreign students	100.0%	51.3%	15.1%
Number	804,420[a]	413,040[a]	121,780[b]
U.S. exports of travel for educational purposes (billion $'s)	$42.6[c]	$21.9	$6.5

Sources: [a] NSF 2019, [b] Zwetsloot 2020, [c] STPI BEA n.d. a

b. Costs of Tuition and Room and Board

We estimate that in 2018 all foreign STEM students in undergraduate and master's degree programs spent from $5.8 billion to $10.1 billion for tuition in the United States (Table 22). We estimate Chinese students spent from $1.6 billion to $2.8 billion. We estimate that in 2018 all foreign STEM students in undergraduate and master's degree programs spent from $9.1 billion to $13.9 billion for room, board, and tuition in the United States and Chinese students spent from $2.5 billion to $3.9 billion (Table 22). These estimates fall comfortably within our estimates of travel to the United States for educational purposes from U.S. statistics on foreign transactions.

Table 22. STPI Estimates of the Value of Expenditures by All International and Chinese STEM Students on Tuition and Room and Board at Colleges and Universities in the United States in 2018

	Total High	Total Low	Chinese High	Chinese Low
STEM undergraduates and associates	179,440[a]	179,400[a]	45,720[b]	45,720[b]
STEM master's	124,337[c]	124,337[c]	40,484[b]	40,484[b]

	Total High	Total Low	Chinese High	Chinese Low
Undergraduate private college tuition[d]	$35,680		$35,680	
Master's private college tuition[d]	$30,070		$30,070	
Out-of-state public university undergraduate tuition[d]		$26,200		$26,200
Out-of-state public university master's tuition [d]		$8,760		$8,760
Foreign STEM undergraduate tuition expenditures (billion $'s)	$6.4	$4.7	$1.6	$1.2
Foreign STEM master's tuition expenditures (billion $'s)	$3.7	$1.1	$1.2	$0.4
Foreign STEM expenditures on tuition, total (billion $'s)	$10.1	$5.8	$2.8	$1.6
Undergraduate private college tuition and room and board[d]	$48,290		$48,290	
Master's private college tuition and room and board[d]	$41,990		$41,990	
Out-of-state public university undergraduate tuition and room and board[d]		$37,390		$37,390
Out-of-state public university master's tuition and room and board[d]		$19,050		$19,050
Foreign STEM undergraduate total expenditures (billion $'s)	$8.7	$6.7	$2.2	$1.7
Foreign STEM master's total expenditures (billion $'s)	$5.2	$2.4	$1.7	$0.8
Total (billion $'s)	**$13.9**	**$9.1**	**$3.9**	**$2.5**

Sources: [a] NSF 2019, [b] Zwetsloot 2020 [c] STPI estimates based on extrapolations from NSF 2019 and Zwetsloot 2020, [d] College Board 2019

E. Findings

1. In 2019, foreign STEM talent contributed $367 billion to $409 billion to U.S. GDP through their labor, or 1.7 to 1.9 percent of U.S. GDP.
2. Increases in total factor productivity are a major driver of increases in per capita incomes in the United States and globally. We estimate that in 2019, foreign-born STEM talent contributed $43 billion to U.S. GDP through their contributions to innovations that have increased U.S. total factor productivity.
3. We estimate that the value-added generated by companies that foreign-born entrepreneurs have helped found in R&D-intensive industries ranges from $260 billion to $394 billion, or 1.2 to 1.8 percent of 2019 GDP.

4. We estimate that in 2018 foreign STEM students spent $22 billion on travel and other costs for educational purposes in the United States. We estimate that foreign STEM students in undergraduate and master's degree programs spent from $9 billion to $14 billion on tuition and room and board in the United States.

Table 23 provides a summary of these economic contributions.

Table 23. STPI Estimates of Various Foreign STEM Talent's Economic Contributions to U.S. GDP (Billions of 2019 dollars)

	Year	Low	Low (% of GDP)	High (billions of $'s)	High (% of GDP)
Labor	2019	$367	1.7%	$409	1.9%
TFP	2019	$43	0.2%		
R&D-Intensive Industries	2019	$260	1.2%	$394	1.8%
Educational travel services	2018	$22	0.1%		

Sources: STPI estimates.

Note: These estimates are not additive; they are the product of several different approaches to estimating the contribution of foreign STEM talent to the U.S. economy.

Nominal GDP in 2019 was $21,433.2 billion.

4. Costs of Misappropriation of U.S. Trade Secrets and Academic Malfeasance by Foreign STEM Talent in the United States

Several organizations have highlighted economic costs to the United States inflicted by China and other countries through copyright, trademark, and patent infringements and misappropriation of trade secrets (USITC 2011; Commission 2013, 2017; OECD 2019; USTR 2021). The purpose of this chapter is to identify and quantify economic costs from these activities and academic malfeasance linked to foreign STEM talent in the United States. We first review losses to the United States from the expropriation of U.S. IP by foreign countries and their citizens, focusing on China. We follow with a discussion of the possible roles of foreign STEM talent, including students, visiting faculty members, and other visitors, in inflicting losses associated with infringements of U.S. intellectual property rights (IPR). We then review instances of academic malfeasance linked to foreign STEM talent in the United States. We conclude by estimating some of these costs.

A. Economic Losses to the United States from the Expropriation of U.S. Intellectual Property

The United States International Trade Commission (USITC), U.S. corporations and their associations, and other private organizations have documented and estimated the losses of the expropriation of U.S. IP by other countries or their citizens. For example, U.S. intelligence services estimated losses from economic espionage, including the theft of IP at as much as $300 billion in 2010 (Garamone 2010). Below, we review findings on economic losses of some of the more prominent of these studies: *China: Effects of Intellectual Property Infringement and Indigenous Innovation Policies on the U.S. Economy* (USITC 2011), *Trends in Trade in Counterfeit and Pirated Goods* (OECD 2016, OECD 2019), and *The Report by the Commission on the Theft of American Intellectual Property* (Commission 2013), and an update to that report, *The Theft of American Intellectual Property: Reassessments of the Challenge and U.S. Policy: Update to the IP Commission Report* (Commission 2017).

China is a particular focus of these studies, as it has been found to be the primary global source of counterfeit or pirated products. The Organisation of Economic Co-operation and Development (OECD) found that in 2016 China and Hong Kong were by far the biggest source of these products, together accounting for 63.4 percent of global exports of these products by value (OECD 2019). According to the Office of the United States

Trade Representative, China and Hong Kong accounted for 92 percent of the value (measured by manufacturer's suggested retail price) and 83 percent of the volume of counterfeit and pirated goods seized by U.S. Customs and Border Protection (CBP) in 2019; both the value and share of total seizures of counterfeit goods seized by CBP originating from China rose in 2019 (USTR 2021).

1. Estimates of Losses to the United States from Illicit Chinese Activities from the USITC Study

The USITC study groups losses because of Chinese infringement of U.S. companies' IPR into four categories (USITC 2011):

1. Copyright infringement (also described as piracy);
2. Trademark infringement (also described as counterfeiting);
3. Patent infringement; and
4. Misappropriation of trade secrets.

Some of these losses stem from the purposeful activities by the Chinese government and affiliated organizations. Others stem from the activities of private Chinese companies and individuals that the Chinese government fails to discourage.

USITC attempted to measure losses through three approaches. The first consisted of a large survey of 5,051 U.S. companies in industries that rely heavily on IP; the survey inquired about their experiences with loss of revenues due to the theft of their IP by Chinese entities. The second consisted of simulations of potential economic gains to the United States, if China were to adopt and enforce protections of IP similar to those of the United States. The simulations employed a model of differential effects on U.S. trade of varying levels of IP protection estimated using econometric techniques. In a third approach, the USITC conducted five case studies of the effects of Chinese government policies on the development of industries that compete with more established competitors in the United States and Europe.

Table 24 shows USITC estimates of losses related to the infringement of U.S. companies' IPR by Chinese entities employing the first approach. Companies reported the largest losses were associated with copyright infringement, primarily the sale of pirated U.S. software. Trademark infringement, especially for consumer goods, was also a major source of losses. When concerns were tallied by number, however, the top IP-related concerns were stolen trade secrets; lost sales, royalties, or license fees; damage to brands or product reputation; and the losses of IPR enforcement.

Table 24. USITC Estimates of Losses to U.S. Companies Stemming from the Infringement of U.S. Intellectual Property Rights in 2009

Type of Loss	Range	Point Estimate	Point Estimate
	(2009 dollars, in billions)	(2009 dollars, in billions)	(2019 dollars, in billions)
Copyright infringement	$10.2–37.3	$23.7	$28.0
Trademark infringement (counterfeiting)	$1.4–12.5	$6.1	$7.2
Patent infringement	$0.2–2.8	$1.3	$1.5
Misappropriation of trade secrets	$0.2–2.4	$1.1	$1.3
Unspecified losses due to infringement	$2.2–35.5	$16.0	$18.9
Expenses incurred to combat Infringement	$0.3–9.4	$4.8	$5.7
Total	**$14.2–90.5**	**$48.2**	**$57.0**

Source: USITC 2011 p. xv

Under its second approach, USITC made two sets of projections of the benefits that the United States might enjoy if China were to adopt and enforce protections of IP similar to those of the United States. The first projection assumes the United States is at full employment. The second assumes there is underutilized capacity in both U.S. labor and capital markets. Table 25 shows point estimates for both scenarios for increases in exports, increases in economic welfare, increases in profits, and changes in employment. (Employment in Scenario 1 does not change by assumption.) The increases in these economic measures under Scenario 2 are large, including an increase in economic welfare of $219 billion in 2019 dollars ($185 billion in 2009 dollars), 1.28 percent of U.S. GDP in 2009, and gains in employment of 2.1 million jobs. However, we have difficulty in translating these potential benefits—or opportunity costs to the United States of China's approach to enforcing IPR—into losses that could be ascribed to the activities of foreign STEM talent in the United States. Consequently, we do not employ these projections in our estimates of potential net benefits and costs of foreign STEM talent in the United States.

Table 25. USITC Estimates of Potential U.S. Gains from Improvements in the Treatment of IPR by China (2019 dollars, in billions)

Economic Measure	Scenario 1[a]	Scenario 2[b]
Increases in U.S. economic welfare	$8	$219
Percent increase in U.S. GDP	0.05%	1.28%
Increases in exports	$126	$126
Increases in employment	-----	2.1 million
Increases in profits	$15	$73

Source: USITC 2011 p. xix

Notes:

[a] Scenario 1 assumes that the United States is at full employment and fully uses the existing capital stock.

[b] Scenario 2 assumes that the United States is at less than full employment and has underutilized capital. Original numbers for 2009 were inflated to 2019 dollars using the U.S. GDP deflator. Percentages of GDP were calculated for 2009.

2. Estimates of Global Losses from Copyright and Trademark Infringement by the OECD

In 2008, the OECD embarked on an effort to estimate global losses from piracy (infringement of copyrights) and counterfeit goods (infringement of trademarks) in international trade based on seizures of these products by customs and other enforcement agencies (OECD 2008). It estimated that globally trade in counterfeit pirated and products rose from as much as $200 billion in 2005 to as much as $509 billion in 2016, a 254 percent increase (OECD 2008; OECD 2019), as shown in Table 26. These estimates are not directly comparable to the USITC estimates because the OECD estimates do not include domestically produced and consumed counterfeit and pirated products, which are substantial in China and other developing countries, or pirated digital products distributed over the internet (OECD 2019).

We do not use these values for trade in counterfeit and pirated products in our estimates of economic losses from foreign STEM talent in the United States. First and foremost, counterfeit and pirated products are manufactured and sold in the countries engaged in these illegal activities, not by foreign STEM talent located in the United States. Second, these values are not equivalent to economic losses to manufacturers or the countries of origin of the manufacturers. Many customers of counterfeit or pirated goods would choose not to purchase the legitimate alternative if the counterfeit or pirated goods were not available because the price would be substantially higher. The Commission on the Theft of American Intellectual Property (Commission) estimates that companies that own the infringed copyrights or trademarks would be likely to capture only 20 percent of the quantity of estimated sales of counterfeit and pirated products because of the higher prices of the legitimate products (Commission 2017).

Table 26. OECD Estimates of Global Trade in Pirated and Counterfeit Goods

2005	2007	2013	2016
$200 billion	$250 billion	$461 billion	$509 billion

Source: OECD 2009, OECD 2019

3. The Commission on the Theft of American Intellectual Property's Estimates of Losses to the United States

The Commission estimates that annual global losses to the United States from counterfeit goods, pirated software, and theft of trade secrets costs exceed $225 billion and could be as high as $600 billion (Commission 2017), as shown in Table 27. In contrast to the USITC numbers, the Commission's estimates of losses to the United States are from the entire world, not just China. The Commission drew on a variety of sources for this conclusion. The Commission first estimated the value of IP theft by adding the value of counterfeit goods imported into the United States and then adding to that figure the value of global goods masquerading as U.S. exports. The Commission estimated the value of counterfeit and pirated tangible goods imported into the United States in 2015 using the OECD estimate for 2013 of the share of global trade accounted for by these products (OECD 2016). The Commission applied this share, 2.5 percent, to total U.S. imports to estimate that the United States likely imported at least $58 billion in counterfeit and pirated tangible goods in 2015. The Commission also estimated U.S. imports of counterfeit and pirated tangible goods using the percentage of such imports into the European Union (roughly 5 percent), under the argument that EU import patterns are likely to be closer to those in the United States than the global average. Using the EU share of roughly 5 percent, the value of imports of counterfeit and pirated goods would have been $118 billion in 2015 (Commission 2017).

U.S. companies suffer losses from the substitution of counterfeit and pirated goods for exports of the original U.S. products. The OECD found that counterfeit and pirated goods masquerading as the original U.S. product accounted for nearly 20 percent of the value of reported worldwide seizures of such goods (OECD 2016). In 2015, total worldwide seizures of counterfeit goods were an estimated $425 billion; 20 percent of that total was $85 billion of counterfeit U.S. goods (Commission 2017). Adding this figure to those for imports yields a range of $143 billion to $203 billion of U.S. trade in counterfeit and pirated goods (Table 27).

Table 27. Estimates of Global U.S. Losses from the Theft of U.S. IP Cited by the Commission on the Theft of American Intellectual Property (2015 dollars)

Economic Measure	Loss (Low)	Loss (High)	Year	Source
Value of U.S. imports of counterfeit and pirated goods	$58 billion	$118 billion	2015	Estimated from OECD
Value of exports of counterfeit and pirated U.S. goods	$85 billion	$85 billion	2015	Estimated from OECD
Total of imports and exports	*$143 billion*	*$203 billion*	*2015*	*Estimated from OECD*
U.S. losses (20% of totals for imports and exports)	$29 billion	$41 billion		
Sales of pirated U.S. software	$18 billion	$18 billion	2015	Estimated from BSA
Stolen trade secrets	$180 billion	$540 billion	2014	Center for Responsible Enterprise and Trade, PricewaterhouseCoopers
Total	**$225 billion**	**$600 billion**	**2015**	**Commission**

Sources: OECD 2016; BSA 2015; Center for Responsible Enterprise and Trade, PricewaterhouseCoopers 2014; Commission 2017

The Commission notes that the value of imports of counterfeit and pirated goods is greater than lost sales by the original manufacturers because many of the customers of such goods would not purchase the legitimate alternatives because the prices are so much higher. Assuming that U.S. manufacturers would only capture 20 percent of the value of counterfeit and pirated imports and exports, the Commission estimates total losses to U.S. manufacturers of $29 billion and $41 billion, 20 percent of the estimates of $143 billion and $203 billion in total U.S. trade in counterfeit and pirated goods, respectively.

The Commission also estimated costs to the United States from sales of pirated software. It drew on a study by the Business Software Alliance (BSA) and International Data Corporation that estimated that the value of the global illegal software market was $52.2 billion in 2015 (BSA 2016). Using this figure, the Commission estimated that the cost of this illegal market to U.S. firms alone was $18 billion (Commission 2017).

The Commission drew on a study by the Center for Responsible Enterprise and Trade and PricewaterhouseCoopers (2014), which estimated that the annual losses of trade secret theft run between 1 and 3 percent of U.S. GDP. Using these figures, the Commission estimated that losses due to trade secret theft ran between $180 billion and $540 billion in 2015 (Table 27).

The largest share of the Commission's estimates of total economic losses from the theft of U.S. IP pertains to the misappropriation of U.S. trade secrets. Some of the larger estimates of losses from the misappropriation of U.S. trade secrets differ from those due to copyright, patent, and trademark infringement. The latter are based on retrospective data: customs seizures or actual sales of counterfeit or pirated products. In contrast, some of the larger estimates of losses ascribed to stolen trade secrets appear to be based on the costs of developing the technology, which are equated with the technology's value (Commission 2017; FBI n.d.).

The cost of developing a technology is not the same as the loss from the theft of the technology. To use a term from economics, technologies are non-rival: even if a technology has been stolen, the original owner can still use it (Romer 1990). In contrast, the consumption of rival products, like sandwiches or gasoline, precludes their use by anyone else. Because technologies are non-rival, the owner of the trade secret only suffers a loss if the thief makes use of it. If the thief is unable to use the technology to manufacture a product or improve its production processes or fails to sell the technology to a buyer who does, the owner of the technology does not suffer a loss. The difference between value and loss may explain the wide difference between the estimates of losses (for China only) due to misappropriation of trade secrets based on the USITC survey—$0.2 billion to $2.4 billion—and the much larger values (for all countries) cited by the Commission—$225 billion to $600 billion.

In other words, as with estimates of losses from infringements of copyrights, trademarks, and patents, lost sales are the appropriate metric for estimating economic losses from the misappropriation of trade secrets. Because losses are only incurred if the thief is able to translate the stolen trade secrets into businesses that successfully compete with the owner of the IP, we did not use the numbers on losses stemming from the theft of trade secrets cited by the Commission because they appeared to be based on the cost of developing the technologies, not on lost sales due to the misappropriation of trade secrets.

B. Potential Roles of Foreign STEM Talent in the United States on Infringements of IPR of U.S. Companies

Some of the losses to the United States cited above are large. In this section, we crosswalk these estimates of losses generated by illicit activities with possible roles of foreign STEM talent in the United States in inflicting these losses. Except for the misappropriation of trade secrets, we do not find readily apparent ways through which foreign STEM talent in the United States is likely to be imposing these losses on the United States.

1. Copyright Infringement

Most of the losses identified by USITC and the Commission involving copyright infringement concern the resale of software without paying royalties to the owner (USITC 2011; Commission 2013; BSA 2015). In many instances, the infringer obtains the original software, including through purchase, and then resells the software, in some cases altering it so that features that would have prevented unauthorized use are disabled (USITC 2011; Commission 2013).

Most infringers sell from their home countries, not from the United States. As most of the sales of pirated software take place outside the United States, foreign STEM talent in the United States does not play a major role in this activity, although it may play a role in stealing some proprietary software. However, we categorize that activity under misappropriation of trade secrets below.

2. Trademark Infringement

Trademark infringement or counterfeiting involves selling a product under a trademark owned by another company. Some products are almost identical to the actual trademarked product; others are much inferior (USITC 2011). Counterfeit products are generally manufactured and labeled outside the United States, although counterfeiters sell into the United States (USITC 2011). Some U.S.-based individuals or companies also infringe on trademarks.

Because much of the production of counterfeit products takes place outside the United States, foreign STEM talent in the United States is not a position to play a major role in these activities. Although we cannot preclude that foreign STEM talent in the United States engages in U.S.-based activities, which infringe on trademarks, like printing T-shirts or selling paraphernalia with the logos of the National Football League, we found no evidence that they are more likely to do so than U.S.-born STEM talent.

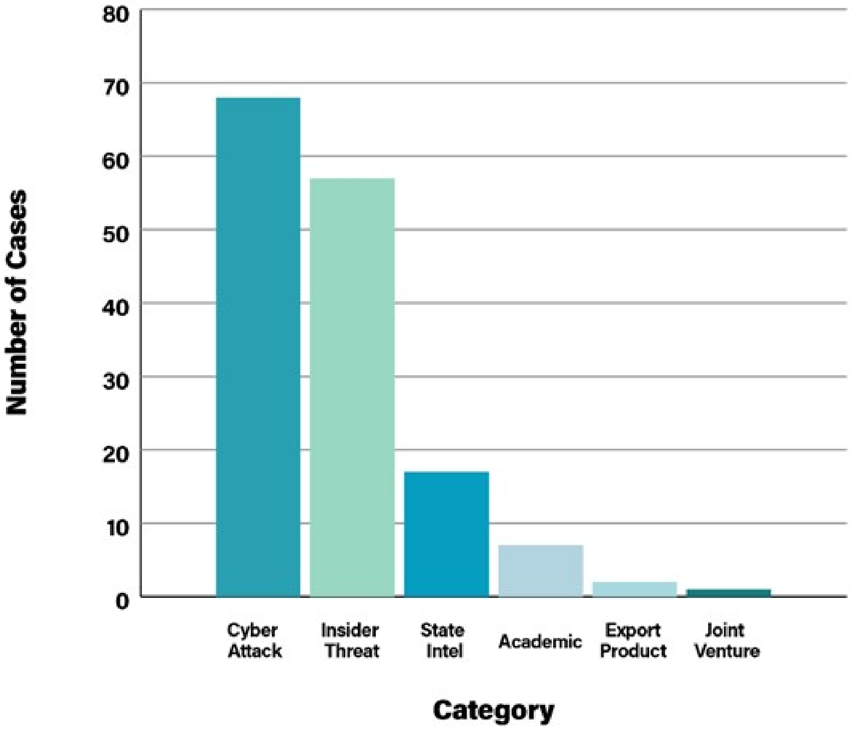
3. Patent Infringement

Patents provide information to the public about the technology being patented; governments protect the IPR of the patent holder through enforcement activities. The U.S. Government has established an effective system for protecting the IPR of U.S. patent holders within the United States. However, outside the United States, some governments, including China's, have not set up such an effective system for protecting patents, often especially for foreign patent holders. China has, in fact, created a form of patenting, called utility patenting, that provides opportunities for Chinese patent holders to usurp the IP of foreign patent holders, including those from the United States (Commission 2013).

Because a patent application, which is made public, must contain sufficient information so that manufacturers of competing products are made aware of protected product features or processes, manufacturers outside the United States have access to information from the patent itself that may permit them to replicate the product or process. Consequently, foreign violators of U.S. patents do not need foreign STEM talent in the United States to obtain information that they might need to recreate the product. Consequently, the role of foreign STEM talent in the United States in infringing patents is likely negligible.

4. Misappropriation of Trade Secrets

Trade secrets are misappropriated through a variety of means: cyber-attacks, industrial espionage, reverse engineering, breaches of former employees' confidentiality clauses, purchases of purloined designs from employees, among other avenues. Foreign STEM talent, especially individuals employed by U.S. companies, have been caught, prosecuted, and convicted for stealing trade secrets (Commission 2013). For example, foreign-born employees of Boeing and Ford were convicted of stealing trade secrets, which they gave or sold to foreign governments or companies (Commission 2013). U.S.-born employees have also been convicted of misappropriating trade secrets.



Source: STPI analysis of CSIS 2021

Notes: We define "insider threat" as individuals who worked or had access to the institution. We define "academic" as students, doctoral candidates, post-doctoral fellows, and visiting professors and scholars.

Figure 2. Means by Which Trade Secrets Have Been Misappropriated Based on CSIS Data on U.S. Court Cases

CSIS has collected information on the means by which trade secrets have been misappropriated for Chinese entities based on information from U.S. court cases (CSIS 2021). The dataset contains "160 publicly reported instances of Chinese espionage directed at the United States since 2000" (CSIS 2021). It includes charges and convictions for various crimes, such as economic espionage, conspiracy to commit economic espionage, theft of trade secrets, conspiracy to steal trade secrets, and other forms of fraud. Not included in the dataset is espionage against U.S. firms or persons located in China, attempts to smuggle munitions or controlled technologies out of the United States, or "1200 cases of intellectual property theft litigation brought by U.S. companies against Chinese entities in either the U.S. or Chinese legal systems." Each instance in the data represents one or more charges and may involve one or more people.

We coded the CSIS court case data by means of acquisition. As shown in Figure 2, we found that the most common means of acquisition has been through cyber-attacks (68 cases), followed by insider threats, that is misappropriation by an employee or other individual working with the company (57 cases). Acquisition from individuals in academia (students or professors) was limited, 7 out of a total of 152 cases. According to U.S. intelligence services, cyber-attacks are now the most common method of stealing U.S. trade secrets (NCSC 2018), not the use of foreign STEM talent, especially foreign STEM talent not employed by U.S. firms.

C. Estimating Losses from the Theft of Trade Secrets

1. Estimates of Losses from the Misappropriation of Trade Secrets by Foreign-born STEM Talent Based on USITC Estimates

Some foreign STEM talent in the United States have misappropriated U.S. trade secrets, primarily foreign-born STEM workers employed by U.S. companies (CSIS 2021). Some visiting researchers and other visitors temporarily in the United States have also misappropriated U.S. trade secrets. Based on the lack of reported cases, foreign STEM bachelor's and master's students do not appear to play a role in the misappropriation of trade secrets, in part because these students have minimal access to companies or research laboratories compared to other foreign STEM talent (CSIS 2021).

We drew on the USITC (2011) estimates of losses associated with the misappropriation of trade secrets by Chinese entities to estimate potential losses from the misappropriation of trade secrets by Chinese STEM talent in the United States. We couple these estimates with information from the CSIS survey of court cases involving misappropriation of trade secrets and economic espionage for our analysis.

Although China's misappropriation of U.S. trade secrets has reportedly grown since 2009, the time of the USITC survey, most of the increase consists of cybercrimes (NCSC 2018). Because we were unable to find estimates of these losses based on more recent survey data, we use the USITC estimates despite the time elapsed since the USITC survey was conducted.

Drawing on the CSIS survey of court cases involving the misappropriation of U.S. trade secrets and other violations, we found 57 instances that we label "insider threats." In these cases, employees of the company used their access to company trade secrets to transfer, or attempt to transfer, them to companies or other organizations in China. Some of these individuals were born in the United States and some in China. Most of the cases we identified involved individuals who were naturalized citizens or permanent residents and involved the loss of a number of trade secrets. Cases of insider threats constituted 37.5 percent of total cases.

Table 28. Expected Economic Losses from Insider Misappropriation of Trade Secrets Related to China

	Low	High	Average
Total (2009 dollars)	$0.2 billion	$2.4 billion	$1.1 billion
Total (2019 dollars)	$0.24 billion	$2.84 billion	$1.3 billion
Share ascribed to foreign STEM talent in the United States	35%	35%	35%
Estimated loss due to foreign STEM talent in the United States (2019 dollars)	$0.08 billion	$0.99 billion	$0.45 billion
Expected loss per Chinese STEM worker in the United States (Low estimate—291,715)	$284	$3,403	$1,560
Expected loss per Chinese STEM worker in the United States (High estimate—325,090)	$254	$3,053	$1,399

Source: Based on USITC (2011) and STPI analysis of CSIS 2021

Notes: 2009 dollars inflated to 2019 dollars using U.S. GDP deflator (BEA n.d.)

We do not mean to imply that any given individual will actually misappropriate trade secrets and cause this level of harm. We provide this rough average per person mainly as an apples-to-apples comparison with the annual value of each individual's labor.

We multiplied the USITC estimates of losses from the misappropriation of trade secrets by China by this percentage (Table 28) to generate estimates of losses due to misappropriation by insiders. We then generated two estimates of total number of STEM workers in the United States born in China.[19] We divided the USITC estimates of losses ascribed to insiders by the number of STEM workers in the United States born in China to generate an average loss per worker. Our estimates range from an average loss of $284 2019 dollars per STEM worker born in China at the low end to $3,403 at the high end; the average expected loss was $1,560 (Table 28).

We note there are several drawbacks to these estimates. First, individuals born in the United States, not just in China, have misappropriated trade secrets, which biases the estimate upwards. Each case of misappropriation often involves more than one Chinese-

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[19] There are between 2.6 million to 2.9 million foreign-born STEM workers in the United States. We do not know the share of those workers born in China. However, we do know that 11.1 percent of PhDs working in STEM occupations the United States were born in China (Chapter 2: Table 4). If we apply that percentage to the numbers of foreign-born STEM workers, we generate two estimates of the size of the Chinese STEM workforce in the United States—291,715 and 325,090.

born individual, which biases the estimate downwards. Second, as noted above, the USITC survey is from 2009. Misappropriation of U.S. trade secrets by Chinese entities has been on the rise since that date, which imparts a downward bias to these estimates.

2. Value of Misappropriated Trade Secrets from Court Cases

We used the CSIS survey data to estimate potential ranges of the value of individual instances of misappropriations of trade secrets. We employ these estimates in our net assessments in Chapter 6. For 17 of the court cases in CSIS survey we were able to find some form of damages. In Table 29, we list estimates of the alleged harm, which the victim companies provided in court documents as the amount of R&D funds they expended to create the trade secret. Notably, none of these estimates is for lost revenues. Where possible, we also list the amount of restitution that a convicted individual had to pay the company: restitution is equal to the benefit the court determined that the individual personally gained from their crime. The survey did not list information on the amount of "compensation" that a convicted individual had to pay the victimized company, which is the court-determined amount of economic harm that the victim company suffered.

We use the medians from the two columns for alleged harms and restitution to estimate the costs per incident of misappropriations of trade secrets. The median of the "Alleged Harm" column is $57.5 million, which we use for our high estimate, and we used the median of the "Restitution" column—$420,000—for our low estimate.

The two highest value cases we found alleged harms of about $1 billion dollars. These damages seem unrealistically high and deserve a brief discussion. In the case of Tao Li and Yu Xue, who stole trade secrets from GlaxoSmithKline (GSK), both scientists pleaded guilty. Yet, despite being convicted, "Judge Joel Harvey Slomsky said federal prosecutors failed to convince him that GSK suffered a financial loss" (Sagonowsky 2021). This underscores the tenuous relationship between the amount of R&D funding used to create a trade secret and the losses associated with transferal of the secret to a competing party. In the case of Hongjin Tan, who stole trade secrets from Phillips 66 with the intention of transferring them to a Chinese company, the judge ordered only $150,000 in restitution (Sun 2020). In other words, the Chinese company to which Tan was attempting to transfer this trade secret was only willing to pay about $150,000 for it. The alleged harms from the remaining cases range from $700,000 to $120 million.

Table 29. Economic Harms from A Selection of Trade Secret Court Cases Involving China

Instance of Potential Theft	Alleged Harm[a]	Restitution[b]
Tao Li and Yu Xue	$1,000,000,000	
Hongjin Tan from Phillips 66	$1,000,000,000	$150,000
Xiaorong You from Coca Cola	$120,000,000	
Xiwen Huang[c]	$107,500,000	$114,275
Xiang Dong Yu	$75,000,000	
Chunlai Yang	$75,000,000	
Chen Zhengkun on behalf of United Microelectronics Corporation (UMC)[d]		$60,000,000
Shanshan Du	$40,000,000	
Mo Hailong and five others	$35,000,000	
Kexue Huang	$13,500,000	
Ji Li Huang and Xiao Guang Qi	$7,000,000	
Yan Ming Shan	$700,000	
Wen Chyu Liu		$600,000
Wei Pang and Hao Zhang		$476,835
Hao Zhang		$476,835
Yi-Chi Shih and Kiet Ahn Mai		$362,698
Shan Shi and Gang Liu		$342,425

Source: STPI analysis based on CSIS database

[a] These values are the sum of R&D funds the company spent to develop the lost trade secrets.

[b] These are the damages that the court ordered the convicted individual to pay.

[c] The alleged harm was $65 million to $150 million. We took the average.

[d] This is technically a fine levied against UMC for engaging in corporate espionage. A fine is a penalty primarily meant to discourage bad behavior; the value does not necessarily reflect actual gains by UMC from the trade secrets or losses to the victim company. Regardless, we use it as a form of restitution.

D. Opportunity Costs to the United States Stemming from Academic Fraud Involving Chinese Funding

Principal investigators that commit academic fraud by double dipping—seeking funding from U.S. sources for projects that are already funded by foreign sources—impose opportunity costs on the United States. Researchers who were not funded because the double-dipper won the grant were unable to pursue their proposed research. The United States loses the ability to fund the creation of new knowledge by selecting a different, unfunded project and the value of the U.S. grants going to the double-dipper was lost.

For our analysis of the CSIS dataset, we categorize a perpetrator as an “academic” if the researcher violated the terms of the researcher’s visa or the researcher violated his or her obligation to notify U.S. Government grant-making agencies about connections to Chinese talent programs or the People’s Liberation Army. We identified seven instances that we label "academics." The violations were perpetrated by both U.S.-born and Chinese-born professors. These professors received a number of grants during the period of time of the violations, which often extended over many years. We were able to associate damages with five instances (Table 30). Damages associated with Saw-Teong Ang, who is accused of 42 acts of fraud related to his Federal research, were $1,590,000, for example.

Table 30. Federal R&D Funds Squandered Due to Fraudulent Behavior

Instance of Potential Theft	Damages (Charged)[a]	Damages (Convicted)[b]
Harvard professor Charles Lieber is accused of hiding his involvement with Chinese talent programs, such as establishing a lab at Wuhan University of Technology.	$15,000,000	n/a
Ohio State University professor Song Guo Zheng is accused of hiding his affiliation with Chinese talent programs and research institutions.	$4,100,000	n/a
A researcher at Nationwide Children's Hospital's Research Institute, Li Chen, was convicted of stealing scientific trade secrets and using them to sell products in China (DOJ 2021).	Unknown	$2,600,000
University of Arkansas Professor, Saw-Teong Ang, is charged with 42 counts of wire fraud and two counts of passport fraud for failing to disclose financial ties to Chinese institutions.	$1,590,000	n/a
Texas A&M professor Zhengdong Cheng is accused of fraud for hiding his affiliation with a Chinese company and university while performing aerospace research on a NASA research grant.	$747,000	n/a

Source: CSIS data set

[a] These values are the sum of U.S. Federal R&D awards the professor received during the period of suspected theft.

[b] These are the damages that the court ordered the convicted individual to pay.

Interviewees from NSF and NIH indicated that typical research awards to principal investigators range from $200,000 to $400,000 per year for 3 to 5 years. For the purposes of our estimates of U.S. losses stemming from academic fraud enabled by China, we assume that each instance of fraud imposes an opportunity cost of $400,000 per year over 4 years, $1,600,000—the value of the grant. This number is the same size as the damages associated with Saw-Teong Ang. We use these figures in Chapter 6 to estimate net benefits.

E. Findings

1. Of the four categories of losses stemming from illicit activities by Chinese organizations and businesses, copyright and trademark infringement have been the most costly, according to a survey of businesses.
2. Some estimates of the cost of misappropriated trade secrets appear to conflate the cost of inventing the technology with losses. A survey of businesses found losses stemming from reduced sales were a small fraction of other estimates that appear to be based on the cost of developing the technology.
3. We estimate that the expected loss from the misappropriation of U.S. trade secrets per STEM worker born in China ranges from $254 to $3,403 per year.
4. Our low estimate for the cost per incident of misappropriation of trade secrets is $420,000 and our high estimate is $57.5 million.
5. We estimate that the opportunity cost to the United States of academic fraud involving double dipping, researchers who fund the same research using both Chinese and U.S. research funds, runs on average $1,600,000—the value of the grant—or $400,000 per year over 4 years, the average length of a grant.

5. Costs to the United States of ITT by Foreign STEM Talent

Another source of potential losses to the U.S. economy from foreign STEM talent in the United States is through the transfer of intangible technologies acquired while here to other countries. The transfer of the intangible technologies can contribute to the emergence of industries that compete with existing or potential future U.S. industries.

We define intangible technologies as knowledge about processes, procedures, and operations acquired through working or studying in a specific environment. For example, doctoral students working in a chemistry laboratory learn how the laboratory is managed, how to operate (and fix) complex equipment, and how to efficiently run experiments. Individuals who work in companies learn about industrial processes, the organization of assembly lines, logistics and ordering systems, quality assurance, and how to work with and improve the operations of suppliers.

In this chapter, we first review the economic benefits and costs to the United States from transfers of technologies from the United States to other countries. We then review the various means by which technologies are transferred to other countries, including the roles foreign STEM talent may play in these transfers. We then assess the factors that contribute to the successful emergence of industries that compete with those in the United States and other developed countries. Following that section, we discuss gains from trade and adjustment costs stemming from loss of global and domestic market shares due to the rise of competing industries in part due to the transfer of technologies, including intangible transfers of technology. We then review estimates of gross employment losses in the United States due to imports from China stemming from the rise of competitive industries in that country and estimate gross economic losses to the United States from those imports. We follow this section with a discussion of the possible role of ITT in these costs. We conclude by estimating the value the Chinese government places on ITT through the return of Chinese nationals who have studied or worked abroad.

A. Benefits and Costs of Technology Transfer

1. Benefits to the United States from Transfers of Technology to Other Countries

Transfers of technology are an inherent part of the global economy. Developed countries export machinery and equipment to less developed countries. Many R&D-intensive companies in the United States generate substantial revenues from the sale of licenses. In 2019, U.S. exports of licenses and other charges for the use of U.S. IP were $117 billion. These exports enable the companies to fund more R&D than otherwise would be the case, contributing to their ability to stay at the technological frontier. Professional and management consulting services, an important means by which technologies are transferred, are also an important U.S. export, running $105 billion in 2019.

Exports of machinery and equipment, licenses and other IP, and consulting services are commercial decisions made by businesses. When a sale has been made, the exporter has determined that the revenue is worth more than the potential costs of possibly creating a competitor. Because these decisions have been made on a commercial basis, we find it difficult to argue that these transfers of technologies impose economic costs to the United States. For this reason, we do not estimate costs for these transfers of technical technologies. On the other hand, as discussed in the previous chapter, the theft of technologies through the misappropriation of trade secrets and other theft of IP does impose economic costs on both companies and on the United States.

2. Costs to the United States from Transfers of Intangible Technologies

Intangible technologies are acquired during the course of an individual's study or employment. ITT differ from transfers of tangible technologies because the owner is the individual, not the university or company where the individual studies or works. Institutions do not have property rights to intangible technologies, only the individual does. Consequently, the economic benefits to the United States of these technologies depend on whether individuals remain in the United States or go elsewhere, taking the intangible technologies with them.

We ascribe an economic cost to the United States if the individual leaves the United States and the individual's transfer of intangible technology contributes to the emergence of a new industry that competes with an existing or emerging U.S. industry. The new industry imposes economic costs on the United States if it leads to declines in U.S. output or employment. We do not ascribe an economic cost to the United States just because foreign STEM talent leaves this country. The United States has no claim on foreign STEM talent; individuals are free to return to their country of origin after studying or working here. In fact, the United States frequently makes it difficult to stay through its visa and other immigration policies.

B. Technology Transfer and the Emergence of Competitive New Industries

As discussed above, ITT only imposes costs on the United States if they lead to the emergence of competing industries that result in declines in output or employment in the competing U.S. industry. To assess these potential costs, we first review the various avenues through which technology transfers serve to help develop competing industries, and among those mean avenues, the role of intangible transfers of technology.

1. How Are Technologies Transferred to Other Countries?

Historically, technology transfer has been a necessary but insufficient condition for the development of new industries capable of competing with incumbents. Companies in new industries also need capital, a skilled workforce, marketing networks, and supply chains. Porter (1990) argues that location is also important: innovative firms benefit from being located in clusters where they enjoy network effects, such as links to nearby sources of capital who understand the business, skilled workers, and marketing and supplier networks. Close proximity of people and institutions results in the rapid dissemination of new ideas, skills, and technologies in the industry.

Technology transfer takes place through a number of different avenues, licit and illicit (Table 31). New entrants into an industry use many of these mechanisms, often repeatedly. The various forms of technology transfer are like Lego blocks: no single instance is sufficient to transfer the entire technology to a new company; all are needed to create a successful new industry. Below, we focus on licit means of technology transfer, as we have already discussed illicit means at length in the previous chapter.

Hoekman, Maskus, and Saggi (2005) review the literature on the effectiveness of various avenues of transferring technologies from companies in one country to those in another. They note that the best avenues vary by the ability of the receiving country to effectively absorb the technologies. Among these, imports of machinery and other capital equipment are a primary avenue by which technologies are transferred. Equipment suppliers often train the employees of the purchasing company on how to operate the machinery most efficiently and how best to integrate it into the purchaser's operations. Suppliers frequently sell maintenance contracts and often set up affiliates to service those contracts. They train locals on how to maintain and fix the equipment, another form of technology transfer. In the context of purchasing and operating new equipment, trade shows, conferences, technical literature, and industrial consultants are also beneficial, but are secondary to interactions with the manufacturer.

Customers also play a role in technology transfer, especially through the development of supply chains. Customers frequently work closely with the foreign supplier, transferring technologies for quality assurance, production processes, and logistics so as to ensure that the inputs or products it purchases meet its standards.

Foreign direct investment is another important avenue for technology transfer. Not only does the investor bring an operating production facility into the country, investing companies work with local suppliers, transferring technologies and ways of doing business that increase the efficiency of the local supplier network. Locals who work at the company may move to a local competitor or set up their own businesses in competition with their previous employer, drawing on what they learned from working there.

Table 31. Licit and Illicit Avenues for Technology Transfer

Licit	Illicit
Suppliers of equipment	Cybertheft of designs, corporate information
Foreign direct investment	Former workers breach confidentiality clauses
Joint ventures	Espionage in industrial facilities
Licenses	Designs purchased from current employees
Patents	Reverse engineering of illegally acquired systems
Consultants	Acquisition, investment in companies of interest through front companies
Customers	
Trade shows, conferences	
Trade journals	
R&D collaboration and partnerships	
Worker mobility	
Talent recruitment programs	
ITT from individuals who have studied, trained, or worked abroad	

Source: STPI compiled list

Alternatives to foreign direct investment include joint ventures and licensing. Joint ventures are a form of foreign direct investment in which the foreign investor jointly invests in a new local company with a partner from that country. Each of the partners owns part of the venture. Joint ventures can be useful when the foreign company does not know the local market. More frequently, they are used to avoid or solve potential political problems. In some instances, as in China, the host government may make a joint venture a precondition for operating in the country or the industry.

Licensing is widely used among countries with more developed industrial sectors and strong IP protections. Successful transfers of technologies using licenses require the purchaser to have the capacity to learn and invest to apply technologies to its production processes. Countries that expend substantial amounts on licenses tend to have workforces with strong engineering skills (Yang and Maskus 2001). Owners of IP are less willing to sell licenses to companies in countries that have poor mechanisms for protecting their IPR.

Movements of labor from foreign companies to domestic companies is another avenue for technology transfer. The importance of these movements depends on how developed the industry is in the country. If local firms do not have the capacity to utilize the technology, labor movements play a minor role. In countries like China, where local businesses and their workforces have the ability to absorb the technology, labor turnover can be important as a means of diffusing technologies (Hoekman, Maskus, and Saggi 2005).

The successful creation of competitive new industries depends heavily on the economic and business environment within which companies in these emerging industries operate, not just on technology transfer. Foreign direct investment is more likely to result in the creation of new industries if the country has good infrastructure, an effective legal system, and an open trade and investment regime (World Bank 2004). Good domestic educational systems are important for ensuring that a trained workforce is available to staff emerging industries. Hoekman, Maskus, and Saggi (2005) argue that a capacity for domestic R&D, even if not competitive with those in major R&D centers in developed countries, is important for absorbing and adapting technologies to local conditions. A workforce with sufficient engineering and management skills is instrumental for successful technology transfers.

ITT is important for enabling the creation of new industries, but secondary to imports of machinery, foreign direct investment, and the overall business environment in a country (World Bank 2004). Hoekman, Maskus, and Saggi (2005) note the role played by Indian nationals who returned from the United States in the development of India's software industry, highlighting the importance of training and study abroad for the successful transfer of those technologies. Crane et al. (2021) found that Taiwanese and South Korean nationals who studied and worked in the United States played crucial roles in developing Taiwan's microchip manufacturing industry and Korea's electronics industry. These ITTs are likely to be more important for the creation of new industries than the expansion of competitive industries with traditional technologies. However, attracting individuals who have mastered intangible technologies does not guarantee that a competitive industry will emerge.

2. Factors in the Emergence of New Competitive Industries in China

In recent years, China has successfully developed a number of competitive industries, especially in medium-level technologies. Part of its success has stemmed from its large domestic market. As the world's largest consumer of steel and automobiles, it is not surprising that new steel mills and automobile assembly plants have gravitated to China. China has also benefited from lower-cost labor, which made it possible to undercut foreign incumbent companies on cost (Chow 2015). Over time, success has built on success as large global market shares in products like cell phone equipment, routers, electronics, high voltage transformers, and a wide array of components and products like motor vehicle and construction equipment parts have resulted in the creation of highly efficient supplier networks in China (Lemoine Unal-Kensenci 2004).

Chinese government policies have played a role in the creation of some of these industries, albeit to the detriment of other less-favored industries. It has channeled investment to favored sectors, like steel, through directed, subsidized loans (Haley and Haley 2013). Although such loans help an industry to emerge, they have often led to overcapacity, resulting in industry-wide losses. The Chinese government has adopted "Buy China" policies whereby government procurement is confined to domestic Chinese companies or foreign companies with manufacturing facilities in China. In industries given priority by the Chinese government, foreign companies are not permitted to set up wholly-owned or even majority-owned subsidiaries, but must have a Chinese joint-venture partner. In some instances, the Chinese government has stipulated that the foreign partner transfer technologies to its Chinese partner as a condition for access to the Chinese market (Commission 2017). Because of China's very large market, foreign companies have been more willing to engage in joint ventures under these conditions than in countries with smaller, less attractive markets.

Several foreign companies have had bad experiences with joint ventures in China. In a number of sectors (wind turbines, high-speed rail, and construction equipment, for example), Chinese joint venture partners have stolen the technologies of their foreign partners and used them to manufacture similar products in their own plants (USITC 2011). In the wind turbine and high-speed rail industries, all Chinese government orders or procurement subsidies went to domestic Chinese companies, not joint ventures (USITC 2011). Because of these experiences, virtually all foreign companies investing in China take steps, including delaying the transfer of their most advanced technologies, to limit leakage of their IP (Crane et al. 2014; Moran 1998).

Chinese STEM talent trained at U.S. universities or who have worked in U.S. companies, gaining knowledge of new technologies and know-how, have been a source of ITT. They have contributed to the creation of competing industries—when they have returned home. They appear to have played roles in developing China's capabilities in manufacturing routers and other cellphone equipment and in China's current efforts to create a civil aviation manufacturing industry (Crane et al. 2014).

C. Gains from Trade and Adjustment Costs

The economic costs to the United States from the development of competing industries in other countries occur through the economic adjustments that follow changes in foreign trade. Before reviewing the trade adjustment costs stemming from the rise of competing industries in China in more detail, we first put these costs in context by discussing gains from trade and the net benefits of trade in general to the United States.

1. Gains from Trade

Trade has been a major driver of the historically rapid growth in economic output and per capita incomes in the United States and the rest of the world that has occurred since the end of World War II (OECD 1998). Trade accelerates growth by reallocating resources to more productive uses in the participating economies, thereby increasing aggregate output; broadening output markets so that producers benefit more from economies of scale; increasing consumer welfare through the provision of a wider assortment or lower-cost goods; and facilitating the transfer of technologies, thereby enhancing global productivity.

Imported goods and services benefit U.S. households and companies. Imports satisfy U.S. demand for commodities not produced in the United States. They provide lower-cost or higher quality goods. They expand the assortment of goods available, including goods with different attributes than competing U.S. products. Imported goods provide access to technologies that U.S. manufacturers may lack.

Existing patterns of trade are disrupted when new entrants supply new resources (for example, when a new cobalt mine is opened); are able to manufacture an existing product more cheaply, with better quality, or develop new technologies involving new products or processes; or introduce variants of existing products with new attributes. Changes in global markets and the accompanying adjustment costs are particularly notable when new companies from countries not previously engaged in the industry enter industries that have been dominated by other countries.

Economists have been more successful at measuring declines in gains from trade when barriers to trade are raised than in calculating increases in gains from trade when barriers to trade are lowered. Estimating gains from trade is hard because it is difficult to determine the counterfactual: What would have happened to the U.S. economy if barriers to trade had stayed the same? In contrast, when barriers to trade are raised, economists can more easily measure economic losses after the event.

A series of recent studies of the effects of increases in U.S. tariffs imposed in 2018 illustrate the magnitude of economic losses due to reductions in gains from trade. Amiti et al. (2019) found the 2018 tariff increases raised prices for U.S. consumers and imposed dead weight losses on the U.S. economy, reducing GDP and aggregate U.S. welfare by \$4.6 billion per month—\$55 billion per year or 0.3 percent of 2019 GDP. Flaaen and Pierce (2019) found that the 2018 increases in U.S. tariffs resulted in a reduction in U.S. manufacturing output and employment as the tariffs raised the cost of imported inputs for U.S. manufacturers and because of retaliatory tariffs imposed by China and other U.S. trading partners, making it more difficult for U.S. manufacturers to compete in world markets. They found manufacturers who were highly exposed to the tariffs experienced a reduction in employment of 1.4 percent due to higher input costs and the effects of retaliatory tariffs, which were only partially offset by a 0.3 percent increase in manufacturing employment in the industries that the tariffs were designed to protect. Companies that experienced a sharp increase in tariffs on imports of inputs increased factory-gate prices by 4.1 percent. The increased input costs raised producer prices and reduced employment in manufacturing. The Congressional Budget Office concluded that the increases in tariffs in 2018 would reduce U.S. GDP by 0.5 percent and average real household income by $1,277 in 2020 (CBO 2020). In short, the increases in U.S. tariffs in 2018 resulted in reductions in U.S. manufacturing exports, output, and employment; accelerated producer and consumer price inflation; and diminished household welfare.

In another study, Crucini and Kahn (1996) found that increases in tariffs and the accompanying reduction in gains from trade contributed substantially to the depth of the Great Depression. The Smoot-Hawley tariffs, which were much more extensive than the 2018 tariff increases, subtracted two percentage points per year in GDP throughout the Depression because of losses from gains from trade (Crucini and Kahn 1996).

2. U.S. Gains from Trade with China

China is among the top three trading partners of the United States and the largest source of U.S. imports. The United States enjoys sizeable net gains from trade with China: lower prices for imported goods, increased exports, and higher employment in U.S. export industries (Bai and Stumpner 2019). Lower income groups benefit disproportionately from Chinese imports because they spend a larger share of their income on tradable goods, like clothing and shoes, than middle and upper income groups (Bai and Stumpner 2019).

Although it is difficult to measure the size of these gains from trade with China, the economic effects of increases in U.S. tariffs in 2018 on imports from China provide a measure of losses to the U.S. economy when gains from trade are reduced. In 2017, U.S. exports to China ran $130 billion, by 2019 after the imposition of retaliatory tariffs they had fallen to $106 billion: a fall of 18.1 percent (U.S. Bureau of the Census n.d.). U.S. imports from China also fell, from $505 billion in 2017 to $451 billion in 2019, a 10.8 percent decline (U.S. Bureau of the Census n.d.). The declines in trade and increased costs of imports due to the tariffs and countervailing duties imposed by China resulted in falls in manufacturing output and employment, increased consumer and producer prices, and reduced household welfare (Flaaen and Pierce 2019; Amiti et al. 2019; CBO 2020).

D. Gross Economic Losses to the United States from the Emergence of Competing Industries in China

Not all economic losses to the United States from economic relations with China are driven by illicit activities. The emergence of competitive industries in China that have taken market share from U.S. companies has been cited as a major factor in the loss of industrial output and manufacturing jobs in the United States over the last several decades. Imports of machinery, foreign direct investment, licensing, and the movement of workers to new employers have been important avenues for the transfer of technologies that have contributed to the rise of these industries. ITTs through individuals who have worked and studied abroad, including in the United States, have also played a role, albeit secondary, in the emergence of some of these industries.

In this section, we review estimates of gross economic losses in manufacturing employment and value added to the United States stemming from increased U.S. imports from China. We trace these increases in imports in part to the emergence of increasingly competitive Chinese industries made possible from the transfer of technologies to China, including through the return of Chinese STEM talent. The purpose of this section is to bound possible gross economic losses to the United States from the emergence of these industries.

1. Adjustment Costs Associated with Trade

Gains from trade emerge as factors of production, like labor and capital, shift to sectors where the economy has a comparative advantage and away from sectors where it does not, resulting in net gains in output and aggregate welfare. Although beneficial to sectors that enjoy a comparative advantage, the costs of adjustment in sectors that do not can be painful, as workers in contracting sectors lose their jobs and companies may go bankrupt. Even when companies survive, cost pressures from import competition may constrain wages. Because the closure of large manufacturing plants is so traumatic for local communities and because some closures stem from transfers of production lines to overseas locations, trade has frequently been seen as a major cause of declines in employment in tradeable goods industries, in particular manufacturing over the last several decades. These declines have been large: U.S. manufacturing employment fell from 17.3 million in 2000 to 12.8 million in 2019, a decline of 4.5 million (26 percent) during a period when aggregate employment rose by 18.1 million (13 percent) (BEA n.d. d).

Adjustment is a constant feature of economic life. Demand preferences shift, technologies change, interest rates fluctuate. A number of economic studies have found that declines in U.S. employment in manufacturing have been primarily triggered by technological change and increases in labor productivity, which has reduced demand for labor; shifts in demand, especially towards services and away from manufactured goods; and changes in aggregate demand (Dai, Liu, and Song 2021; Partridge et al. 2017; Baily and Lawrence 2004; Sachs and Shatz 1994; Krugman and Lawrence 1993). Bernard, Jensen, and Schott (2006) attributed 14 percent (0.2 million) of total job losses (1.5 million) in U.S. manufacturing between 1977 to 1997 to import penetration from low-income countries; the other 86 percent was due to other factors.

2. Estimates of Gross U.S. Job Losses Due to Imports from China

Despite the net benefits of trade with China, because of the increases in imports from China and its economic policies that discriminate against foreign companies, China has been seen as a major cause of declines in employment in manufacturing and real wages for production workers in the United States. Autor, Dorn, and Hanson (2013) estimate that 1 million workers or 21 percent of the decline in manufacturing employment of 4.8 million jobs in the United States between 1990 and 2007 was due to competition faced by U.S. companies from increased imports from China. Acemoglu et al. (2016) estimate that imports from China caused 2 million to 2.4 million in U.S. job losses, in services as well as in manufacturing, between 1999 to 2011. Pierce and Schott (2016) did not generate point estimates of declines in jobs due to imports from China, but they did find that the U.S. Government grant of Permanent Normal Trade Relations to China in 2001 contributed to the loss of 3.4 million manufacturing jobs between 2000 and 2007, 20 percent of total employment in manufacturing. These estimates are for gross losses; the authors did not generate estimates of increases in employment due to exports to China.

In contrast, Dai, Liu, and Song (2021) estimate that between 2000 and 2014, only 2 percent (0.1 million jobs) of the decline of 5.1 million jobs in the U.S. manufacturing workforce was due to imports from China. They found improvements in labor productivity to be the dominant cause of those job losses. Although Feenstra and Sasahara (2017) found that between 1995 and 2011 U.S. imports from China led to a reduction in employment of 2.0 million jobs—1.4 million in manufacturing and 0.6 million in services—increases in total U.S. merchandise exports generated an additional 3.7 million jobs, more than offsetting declines in employment due to Chinese imports. Table 32 shows these numbers.

3. Estimates of Gross U.S. Economic Losses from Trade with China

We have attempted to translate these estimates of reductions in jobs stemming from increased imports from China into estimates of gross losses in labor value-added. Where authors have provided estimates of employment growth related to exports, we include those as well to provide net estimates due to trade with China. We generate estimates for two scenarios. In the first scenario, we assume none of the workers who lost their jobs due to import competition found a new job by 2019. Under this assumption, the U.S. economy has suffered a permanent loss of labor value-added from the loss of those jobs.

To estimate these losses, we multiplied the declines in employment associated with Chinese imports by average compensation in manufacturing in 2019, as a worker's compensation is determined by the value-added of his or her labor. Total compensation is the sum of salary and benefits. For our estimate of salaries, we used the OEWS mean national salary for manufacturing workers, which was $72,709 in 2019 (BEA n.d. e). We then used the average share of benefits to total compensation for production workers in the United States from December 2019, which was 28.14 percent, to generate an estimate of mean benefits of $20,460 (BLS 2019b). We then summed the average salary—$72,709—and average benefits—$20,460—to generate an estimate of total compensation for manufacturing production workers of $93,169. We then multiplied this number by the various estimates of job losses in the United States due to imports from China to estimate gross changes in U.S. labor value-added. With the exception of our calculation using estimates of increases in jobs from Feenstra and Sasahara (2017), these calculations only reflect gross, not net declines.

In some cases, the losses are substantial. The column "Losses in Labor Value-Added: Permanent Job Losses" in Table 32 shows our highest gross estimate of losses is $224 billion, based on job loss estimates by Acemoglu et al. (2016). The lowest was $19 billion based on Dai, Liu, and Song (2021). We calculated that gross additions to jobs from exports (not just exports to China) estimated by Feenstra and Sasahara (2017) generated $335 billion in labor value-added. On a net basis (additional jobs minus jobs lost because of imports from China), U.S. labor value-added was $158 billion higher under their estimate.

In the second scenario, we assume that all workers who lost their jobs due to import competition from China were able to find a new job, but at a lower wage as average wages in manufacturing are higher than the U.S. average. As the U.S. unemployment rate in 2019 was 3.5 percent, the lowest rate since 1969, this assumption that workers found new jobs seems plausible (BLS 2020). Under the assumption that all workers who lost their jobs due to Chinese imports found new ones, the net loss in U.S. labor value-added is the difference in compensation between their former jobs and their current jobs. We assume that workers who were laid off due to Chinese imports on average were unable to find another job in manufacturing, but did find a new job that paid the average U.S. salary in 2019. This was $66,781, $5,928 (8.5 percent) less than the average wage in manufacturing—$72,709 (BEA n.d. e). Employing this differential, we calculated net losses in labor value-added for the various estimates assuming workers have been fully reemployed.

The highest estimate based on estimates by Acemoglu et al. (2016) falls to $14.2 billion; the lowest based on estimates by Dai, Liu, and Song (2021) falls to $1.2 billion (Table 32). In some instances, workers in lower-wage manufacturing jobs found higher paid jobs in construction or other occupations; in other instances, wages in the new job were lower.

Table 32. Estimates of U.S. Losses in Labor Value-Added Due to Imports from China

Source	Years	Changes in Employment	Losses in Labor Value-Added: Permanent Job Losses (billion $'s)	Losses in Labor Value-Added: All Workers Find New Jobs (billion $'s)
Autor, Dorn, and Hanson	1990–2007	-1 million	-$93.2	-$5.9
Acemoglu et al.—Low	1999–2011	-2 million	-$186.3	-$11.9
Acemoglu et al.—High	1999–2011	-2.4 million	-$223.6	-$14.2
Feenstra and Sasahara—Losses	1995–2011	-2.0 million	-$186.3	-$11.9
Feenstra and Sasahara—Gains	1995–2011	+3.7 million	+$334.7	N.A.
Feenstra and Sasahara—Net	1995–2011	+1.7 million	+$158.4	N.A.
Dai, Liu, and Song	2000–2014	-0.2 million	-$18.6	-$1.2

Sources: Autor et al. 2013; Acemoglu et al. 2016; Feenstra and Sasahara 2017; Dai et al. 2021

Technology transfers, tangible and intangible, have been important in the rise of these industries. All avenues of technology transfer have been important: imports of modern machinery, foreign direct investment, and transfers of knowledge from suppliers and customers. In some industries, like wind turbines, misappropriation of trade secrets was an important factor (USITC 2011). Intangible transfers of technology to China by Chinese foreign STEM talent who studied or worked in the United States has also played a role in the emergence of new competitive industries, especially those that depend on newer technologies, although secondary to the other avenues of technology transfer cited above.

Intangible transfers of technology by foreign STEM talent who had been in the United States has been of more importance in R&D-intensive industries than more traditional industries. To focus the estimates on the possible effects of technology transfers on U.S. labor markets and gross labor value-added, we made a separate set of estimates for lost U.S. manufacturing jobs in more R&D-intensive U.S. industries over the time periods used by the authors of the studies (Table 33). We ascribed job losses (and lost labor value-added) due to Chinese imports to this group of industries based on the group's share of total losses of U.S. manufacturing jobs. We made estimates under both the scenarios we described above: no worker who lost a job found a new one and all workers who lost their jobs found new ones.

The gross losses range from \$0.5 billion under scenario 2—all workers found new jobs—to \$111 billion under scenario 1—no workers found new jobs. These estimates are gross; on a net basis, the United States has benefited greatly from trade with China despite these trade adjustment costs.

The success of these Chinese industries in expanding exports has not just arisen from transfers of technology from abroad. Factors such as economies of scale due to the vast domestic market in China, the development of efficient supplier networks, and lower-cost labor in China than in the United States have been important. Some of these exports to the United States come from plants opened in China by U.S. companies. Chinese government policies like subsidized financing, government procurement restrictions on purchases of goods manufactured by non-Chinese companies, and other barriers to trade also contributed to the emergence of Chinese industries that compete with U.S. producers. Although we cannot trace the factors that led to the rise of these industries in China, the numbers are indicative of the economic adjustments that technology flows, tangible or intangible, may trigger.

Table 33. Estimates of U.S. Losses in Labor Value-Added Due to Imports from China in More R&D-Intensive Industries

Source	Years	Changes in Total Manufacturing Employment	% of Job Losses in R&D Intensive Industries	Changes in Employment in R&D-Intensive Industries	Losses in Labor Value-Added in R&D-Intensive Industries: Permanent Job Losses (billion $'s)	Losses in Labor Value-Added in R&D-Intensive Industries: No Net Job Losses (billion $'s)
Autor et al.	1990–2007	-1 million	53.2%	-0.5 million	-$49.6	-$3.1
Acemoglu et al.—Low	1999–2011	-2 million	49.8%	-1.0 million	-$92.8	-$5.9
Acemoglu et al.—High	1999–2011	-2.4 million	49.8%	-1.2 million	-$111.3	-$7.1
Feenstra and Sasahara	1995–2011	-2.0 million	47.0%	-0.9 million	-$87.6	-$5.6
Dai et al.	2000–2014	-0.2 million	44.1%	-0.1 million	-$8.2	-$0.5

Sources: Autor et al. 2013; Acemoglu et al. 2016; Feenstra and Sasahara 2017; Dai et al. 2021

Notes:

R&D-intensive or medium R&D-intensive manufacturing industries are: machinery; computer and electronic products; electrical equipment, appliances, and components; motor vehicles, bodies and trailers, and parts; other transportation equipment; chemical products; and plastics and rubber products.

Industries not included in R&D-intensive or medium R&D-intensive manufacturing industries are: wood products; nonmetallic mineral products; primary metals; fabricated metal products; furniture and related products; miscellaneous manufacturing; food and beverage and tobacco products; textile mills and textile product mills; apparel and leather and allied products; paper products; printing and related support activities; and petroleum and coal products.

E. Estimates of the Value of Technology Transfer Based on Chinese Talent Programs

Another way to measure the value of ITT is to determine what a buyer is willing to pay for it. Chinese nationals who have studied or worked in the United States may not only have acquired trade secrets, they also acquire intangible technologies through their experiences attending a U.S. university or working in a U.S. company. To estimate the value the Chinese government ascribes to this ITT from returning Chinese nationals, we estimate the amount of money the Chinese government and Chinese institutions are willing to pay individuals who have acquired intangible technologies in the United States through their work or studies. We base our estimates on payments to returning STEM talent from Chinese talent recruitment programs; these programs are trying to attract Chinese nationals back to China. One of the benefits of attracting these individuals back to China is the intangible knowledge and skills they have acquired abroad. An accurate estimate of the value ascribed to individuals who have been trained or worked in the United States would be the difference between the compensation paid to domestic talent and the compensation paid to foreign-trained talent. We provide sufficient information to make this calculation; however, we ultimately make a more conservative estimate.

Professors in China on average reportedly earn half or less of what their U.S. peers earn (Jia 2018). According to the business intelligence website, Glassdoor, the average salary for a professor in the United States is approximately $110,000. China is likely not interested in attracting merely average talent to their own institutions. On the higher end, Glassdoor reports average salaries at the Ohio State University and Stanford University as $150,000 and $165,000, respectively. For our analysis, we halve the average U.S. salary to approximate a low salary for Chinese professors as $55,000 or about 380,000 RMB.[20] Likewise, we halve the average Ohio State University salary to approximate a high salary for Chinese professors, such as at prestigious Chinese universities, as $75,000 or about 1,040,000 RMB. As a point of reference, a promotional flier for the Tsinghua−Berkeley Shenzhen Institute (TBSI) offers a minimum salary of 400,000 RMB ($58,000), not counting the minimum 200,000 RMB ($29,000) relocation allowance for securing housing. This position appears to be open to domestically trained talent; thus, it provides a partial validation of our range of estimated salaries. Our interviewees indicated that these estimates of compensation are likely too high. Regardless, we provide them for perspective.

To estimate the value that China places on overseas-trained talent, we drew on the compensation packages advertised in English by three Chinese universities in Table 34. For two of the universities, the applicant must have already been accepted into either the

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[20] Unless otherwise noted, this chapter uses the average annual exchange rate between the RMB and the dollar for 2020 of 6.90 as reported by the International Monetary Fund (IMF n.d.).

1000 Talents or the 1000 Young Talents program.[21] According to the advertisement by the Southern University of Science and Technology (SUSTech), "applicants for the 1000 Talents Global Recruitment Program should be a professor or a senior researcher, while applicants for the 1000 Young Talents Global Recruitment Program should have three years or more of overseas post-doctoral research or work experience" (SUSTech n.d.). The compensation amounts listed appear to combine the compensation provided by the central and provincial governments with the compensation provided by the university. The lower levels of compensation seem to correspond to the Young Talents programs—those who are professors or researchers who have at least 3 years of overseas work experience. The higher levels of compensation are for professors and senior researchers who have worked abroad. In contrast, the TBSI does not require applicants to be accepted into a central government or provincial talent program, although applicants who have been accepted into one of these programs "are especially favorably regarded." The university will help its professors apply for acceptance into these talent programs.

An accurate estimate of the value that China places on ITT from overseas-trained individuals would be the difference between the baseline compensation for domestically trained talent and compensation for foreign-trained talent; the value that remains is the value of ITT and potentially TTT as well. However, to arrive at a higher estimate of the value the Chinese government puts on ITT, we assume the total compensation paid to overseas talent is the value the Chinese government ascribes to the ITT they bring (Table 34). In other words, we have set the baseline salary for domestically trained talent to effectively zero. We note that both the salary and the relocation allowances from Talent Programs directly benefit the recruited talent, while the research funding does so only indirectly. Regardless, for this analysis we include the value of the research funding in the total compensation paid to attract the talent. Thus, we assign the minimum value of ITT as an annual salary of 0.75 million RMB ($110,000) plus a one-time bonus of 4.25 million RMB ($620,000).[22] We assign the maximum value of ITT as an annual salary of 1.2 million RMB ($170,000) plus a one-time bonus of 16.5 million RMB ($2,400,000).

According to researchers at CSET, "most Youth Thousand Talents awardees were Chinese post-doctoral researchers or professors working abroad when the Chinese government offered them monetary awards and positions at Chinese research institutions under YTTP [Youth Thousand Talent Program]" (Fedasiuk and Feldgoise 2020). However, there is some indication that "outstanding Ph.D. students can also be recruited in exceptional cases if distinguished achievements were made during the Ph.D. studies" (DSE

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[21] Development Solutions Europe Ltd. (DSE) indicates that in 2019 these talent programs were merged into the new "High-end Foreign Experts Recruitment Plan" (DSE 2020).

[22] We use the maximum values from the minimum value columns.

2019). We assign the low values above to be the high value for ITT ascribed to new doctoral graduates.

We were unable to find relevant data to estimate the value ascribed to ITT for individuals who have skills developed in U.S. industry. Thus, we use the same low and high values that we attribute to professors for these individuals.

Table 34. Benefits Meant to Attract Overseas-Trained Talent to Relocate to China

University	Annual Salary		Relocation Allowances[a]		Research Funding		Other Benefits
	Millions of RMB						
	Min	Max	Min	Max	Min	Max	
Jinan University	0.75[b]	n.a.	2	n.a.	1.5[c]	3.5[c]	Assistance with children's education costs
Tsinghua−Berkeley Shenzhen Institute	0.4	1.2	0.2	3.4	1	10	Grant covers labor costs for one secretary, one lab technician, one post-doc total fellow, one doctoral student, and several masters students
Southern University of Science and Technology	n.a.	n.a.	2.75	4.5	n.a.	12	Tenure track, on-campus apartment, insurance

Source: Jinan University n.d.; TBSI n.d.; SUSTech n.d.

Note: All monetary benefits listed in millions of RMB.

[a] Relocation allowances appear to be a one-time bonus, paid out over the course of 3–5 years, to support the transition of the professor to China.

[b] Sum of 0.5 million annual salary from the state and 0.25 million “living allowance” from the Guangdong government.

[c] The 0.5 million RMB subsidy from the Guangdong government is assumed to be in addition to the 1 to 3 million RMB from the state.

F. Findings

1. Imports of machinery by developing countries from developed countries, coupled with technical support for integrating the machinery into production processes, has been a major avenue through which technologies have been transferred from developed to developing countries. Foreign direct investment has also been important.
2. For development countries, an educated workforce—especially engineers, good infrastructure, and an effective legal system—are needed to effectively transfer technologies. Nationals who have studied and worked abroad are helpful, but not a prerequisite.
3. On balance, the United States is a net beneficiary of trade with China.

4. Over the last few decades, estimates of gross losses of manufacturing employment stemming from imports from China range from 0.2 to 2.4 million. However, by 2019 net losses in employment had disappeared.
5. STPI estimates that on a gross basis, lost manufacturing jobs due to imports from China may have reduced U.S. labor value-added by $20 billion to $220 billion a year. On a net basis, STPI calculates that by 2019 such losses may have been $6 billion to $14 billion.
6. Transfers of intangible technologies from the United States to China by the return of individuals born in China who have worked or studied in the United States may play a partial, secondary role in these losses by transferring technologies that have contributed to the development of competing Chinese industries.
7. Chinese STEM talent who studied or worked in the United States before returning to China appear to have played a secondary role in these gross losses.

6. Estimates of Net Benefits and Losses to the United States from Foreign STEM Talent

In this chapter, we tie the estimates of benefits associated with foreign STEM talent in the United States from Chapter 3 to the estimates of the costs associated with that talent from Chapters 4 and 5 to estimate net benefits or costs. We make these estimates on a per individual basis and at times in aggregate. Where possible, we make separate estimates for STEM talent from China.

A. Methodology

We use event trees to estimate the expected net benefits or costs to the United States from various categories of foreign STEM talent. In this section, we first describe these categories in more detail. We then explain our event-tree approach.

1. Categories of Foreign STEM Talent

We group foreign STEM talent in the United States into the following categories:

- **Short-term STEM visitors** who come to the United States to attend a conference, meet with researchers, or engage in business activities.
- **Foreign-born STEM workers** who work for U.S. companies or research organizations. They contribute to the United States through their labor, contributions to innovation, and entrepreneurial and management talents. If they return to their home country, they are likely to transfer intangible technology they have acquired from their work or studies. They may also misappropriate U.S. trade secrets.
- **STEM post-doctoral fellows and visiting STEM researchers.** STEM post-doctoral fellows participate in and may lead research projects at universities and government laboratories. Visiting STEM researchers do so as well or may pursue their own research. Both have substantial access to facilities and information within these organizations. They acquire knowledge of intangible technologies during their stay. They may also acquire and transfer U.S. trade secrets to their home country.
- **Doctoral STEM students.** Doctoral STEM students conduct research and may receive Federal R&D funding or university scholarships. Although they have less access to trade secrets than foreign STEM talent who work for U.S.

companies, they may misappropriate U.S. trade secrets, if they have access to them. They accrue substantial intangible technology during their sojourn in the United States.

- **Bachelor's** and **master's STEM students** who are pursuing a degree at a U.S. university. We assume bachelor's students and master's students generally do not engage in high-value research. Therefore, they neither have access to trade secrets nor are they likely to accrue substantial intangible technology during their stay in the United States.

Individuals fall into these categories based on the activities in which they engage, not on their method of entry into the United States or visa status.

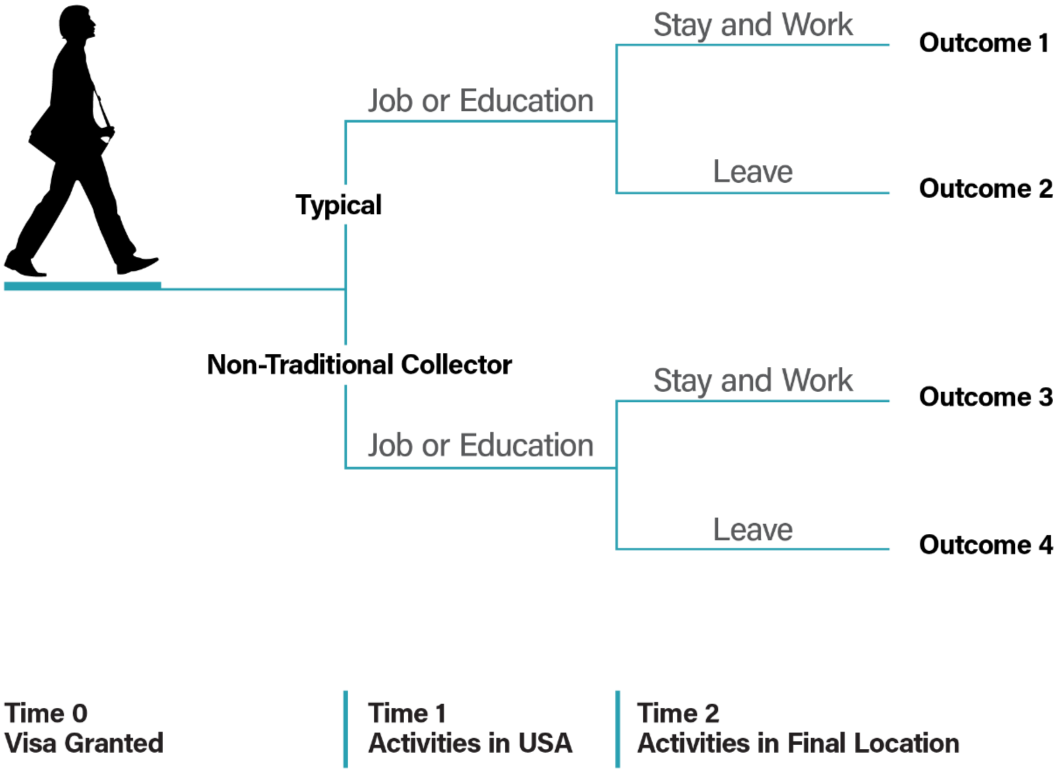
2. Event-Tree Framework

To estimate expected net benefits or costs, we use an event-tree framework (Figure 3). The event-tree approach estimates net benefits or costs at the level of the individual. The event tree consists of "limbs" (the horizontal lines) and "branch points" (the vertical lines). Each limb has a set of associated cost and benefit values, such as the value of the labor performed by the individual or losses due to misappropriation of trade secrets, and the associated probabilities. Each branch point represents a decision, made either by the individual or by the U.S. Government, and has an associated probability for each of the limbs that extend from the branch point. We designate an "outcome" as the expected value of a path through the tree. It is the sum of all limb values along a path multiplied by the product of the branch point probabilities along the path.

We develop a separate event tree for each category of STEM talent with costs, benefits, probabilities, and time steps tailored to the circumstances of the STEM talent. For those individuals who arrive in the United States on a non-immigrant visa, the event tree in effect calculates the expected net benefits or costs of the decision to grant the visa.

We consider three types of benefits and costs that may be present along each limb of the tree. The **value of personnel** is the annual value contributed by an individual to the U.S. economy. This may be measured by the value of a person's labor, the person's contribution to innovation, expenditures on travel, etc. We characterize the value of misappropriated trade secrets and economic espionage as misappropriated **tangible technology transfers** (TTT). We define misappropriated TTT as any information that can be exported as a physical object, such as a blueprint on paper, software on a hard drive, or a piece of hardware. The **value of ITT** is the value of inherent knowledge and other skills leaving the United States. Intangible information resides in a person's head and cannot be copied or transferred easily from one person to another.

In our event trees, individuals first enter the United States and provide value according to the activities that they came to perform. Students attend classes, conducting research if they are graduate students. Short-term visitors attend conferences, visit colleagues, and visit laboratories, among other activities. Some individuals work in U.S. companies, universities, or research organizations. After achieving their initial goals for coming to the United States, they may decide to leave or try to stay. If they are able to stay, they continue to study or work in the United States, generating the associated economic benefits. If they leave, the United States may lose intangible technologies. Whether they leave or stay, they may misappropriate U.S. trade secrets.



Source: STPI

Figure 3. Generic Event Tree

We call foreign individuals engaged in studying or working in STEM fields in the United States, but who misappropriate U.S. trade secrets, non-traditional collectors (NTCs). An NTC is a person "whose primary profession is not intelligence collection but who collect[s] sensitive U.S. technologies and information on behalf of ... government entities" (FBI 2019). NTCs do not have training in obtaining sensitive information. In other words, they are not spies. They may "leverage existing relationships to obtain restricted information outside the scope of the relationship" (National Counterintelligence and Security Center 2017). NTCs include individuals who have openly disclosed their relevant affiliations and those who have an unacknowledged or otherwise undetectable connection to intelligence services or businesses in their home country that have asked them to misappropriate trade secrets.

NTCs face the same decisions as individuals who are not NTCs. However, if a U.S. Government agency detects illicit activities, they are not allowed to stay. If they do stay in the United States, we assume that they remain NTCs and continue to acquire and transfer trade secrets to entities outside the United States. The misappropriation of these trade secrets by foreign entities imposes economic costs on the United States. Appendix D provides a fully traceable example of how we use the event tree to calculate expected values.

3. Estimates of Economic Benefits and Costs per Individual

To calculate the value of STEM workers, visiting researchers, and students to the U.S. economy, we use the estimates of benefits provided by foreign STEM talent from Chapter 3. We use expenditures on hotels and food for short-term visitors; labor compensation for STEM workers and visiting researchers; contributions to total factor productivity for graduate students; and tuition, room, and board for bachelor's and master's students. Table 35 summarizes the most important values from Chapters 3, 4, and 5 that we use as inputs into our expected value calculations.

For a short-term visitor's value to the U.S. economy, we calculate average expenditures on travel. We used BEA statistics on exports of services for expenditures on travel, not including airfares, by business travelers. These data do not include expenditures by individuals who just crossed the border, who worked seasonally in the United States, or were short-term workers (BEA n.d. c.). In 2019, foreign business travelers to the United States spent $28.088 billion under this category. Also in 2019, 9,059,770 visitors to the United States were categorized as business travelers (Pope 2020). Thus, the average expenditure per business traveler was $3,100 per person.

For the value of misappropriated trade secrets associated with STEM workers who are NTCs, we use the values calculated in Chapter 4 from the CSIS data set. We use the average annual value of the U.S. Government research grants to estimate the opportunity costs to the United States from double-dipping by researchers who take money from China for the same research project.

In contrast to the misappropriation of trade secrets, we were unable to generate satisfactory estimates of losses from ITT. We used the estimates we calculated in Chapter 5 of the value the Chinese government ascribes to ITT brought by STEM professionals who return to China as a proxy for these losses. However, this proxy is imperfect. Gains to China from ITT from returning nationals do not equal losses to the United States. For example, the individual may be a surgeon who trained in the United States who uses his or her ITT to save lives in the operating room. The benefit to patients is great, but the surgeries impose no losses on the United States. Moreover, students who come to study in the United States are free to return to their home countries. The United States gains if they stay, but it is hard to argue that a decision by them to return is a loss, especially as the United States does not make it easy for them to acquire permanent residency status.

We assume that the losses associated with misappropriated trade secrets or ITT must materialize within 3 to 5 years of transfer. If the technologies transferred are not put to use in a relatively short time after the return of the individual, the value of the transfer is likely to fall, as the technology ages and is supplanted by newer technologies. For example, assume a researcher returns to his or her home country with valuable misappropriated trade secrets and ITT. Because of the need to attract investment and solve remaining technological hurdles, the researcher may take some years to commercialize his or her knowledge. In the meantime, the researcher's competitors in the United States have made technological progress, reducing the value of the transferred knowledge. As time passes, it becomes less likely that the transfer of the intangible technology is a dominant factor in any inflicted economic losses on the United States.

4. Estimates of Probability of Stay

The probability of stay (P(S)) is the probability that the individual will try to stay in the United States for a second (or third) time step. To estimate these probabilities, we use the NCSES data from Chapter 2 and the literature on Chinese returnees. The measured rates of stay for temporary visa holders from China who receive their STEM doctorates in the United States were 83 percent after spending 5 years in the United States for the 2011 to 2013 cohort and 90 percent after 10 years for the 2006 to 2008 cohort. This is noticeably above the average stay rate for doctorates from other countries, which were 71 percent after 5 years for the 2011 to 2013 cohort and 72 percent after 10 years for the 2006 to 2008 cohort. As our focus is on China, we use the numbers for China. These rates of stay do not include foreign STEM talent who entered the United States on temporary visas and transitioned to a more permanent status during their graduate studies.

Due to the omission of individuals graduating with an immigrant visa or U.S. citizenship, the empirical stay rates are an underestimate; however, we do not know by how much. Approximately 12 percent of foreign-born STEM doctorate earners are permanent residents at the time of graduation; likewise, approximately 9.5 percent are naturalized citizens. The rate of foreign-born students converting from temporary to a permanent status is no more than the sum of these two percentages: 21.5 percent. Accounting for such potential transitions, true stay rates for Chinese-born STEM talent may be 87 percent after 5 years for the 2011 to 2013 cohort and 92 percent after 10 years for the 2006 to 2008 cohort.[23]

We assign Chinese-born doctoral graduates a probability of stay that ranges from 83 percent on the low end to 90 percent on the high end. Lacking a basis to estimate different stay rates for different categories of STEM talent, we apply these probabilities to post-doctoral fellows and foreign-born STEM workers as well.

5. Estimated Probability That an Individual Will Be a Non-Traditional Collector

We did not find any publicly available sources of data that we could use to estimate the probability that an individual is an NTC. Instead, we use a value based on a statement made by William Evanina, who served as director of the National Counterintelligence and Security Center (NCSC) from June 2014 to January 2021. Speaking of Chinese students in 2018, Evanina stated:

> We allow 350,000 or so Chinese students here every year ... that's a lot. We have a very liberal visa policy for them. 99.9 percent of those students are here legitimately and doing great research and helping the global economy. But it is a tool that is used by the Chinese government to facilitate nefarious activity here in the US (Cohen and Marquardt 2019).

In other words, if 99.9 percent of Chinese students are no threat, that leaves 0.1 percent of students as potential NTCs according to Evanina. We were unable to corroborate or validate this number. The statement was likely just illustrative, designed to reassure the public that the vast majority of foreign students in the United States do not have nefarious intentions rather than an actual estimate. Discussions of "nefarious behavior" may include instances that would not be considered crimes. Court cases of theft and fraud against Chinese researchers are frequently dismissed or return not-guilty verdicts. For court cases of economic espionage, defendants were never proven guilty of any serious crime in 21 percent of cases involving individuals born in China, while only 11 percent of such cases involving U.S.-born or foreign-born individuals from Europe or North America were dismissed or returned not-guilty verdicts (Kim 2018). The American Institute of Physics reports that there is growing concern in Congress and academic communities that Federal efforts to secure the U.S. research enterprise are troubled by false accusations and racial profiling of ethnically Chinese individuals (Thomas 2021). Regardless, for the purposes of analysis, we tentatively use Evanina's estimate that 0.1 percent of students will engage in bad behavior, such as being an NTC.

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[23] To estimate the upper bound for stay rates, assume that all students enter their PhD studies on a temporary visa. Then, we take the fraction of students who transition (21.5 percent) and add the fraction of still-temporary students (100 – 21.5 percent) times the appropriate stay rate for temporary visa holders (83 or 90 percent for graduates born in China).

Table 35. Summary of Values Used in Expected Value Calculations

Metric	Category	Low	High	Periodicity
Probability of Stay	Doctoral Students, Post-doctoral Fellows	83%	90%	
Probability of Non-Traditional Collector	All	0.1%	0.1%	
Value of Personnel				
Average Compensation of STEM Worker	Workers, Professors, Post-doctoral Fellows	$139,605	$139,605	Annual
Contribution to increases in GDP from TFP	Workers, Professors, Post-doctoral Fellows, Doctoral Students	$12,225	$13,568	Annual
Tuition, Room, and Board—Bachelor's	Bachelor's Students	$37,390	$48,290	Annual
Tuition, Room, and Board—Master's	Master's Students	$19,050	$41,990	Annual
Travel Expenses	Short-term Visitors	$3,100	$3,100	Per trip
Value of Misappropriated Trade Secrets	STEM Workers	$420,000	$57,500,000	Instance
Opportunity Cost of Academic Fraud	Professors	$400,000	$800,000	Annual
Intangible Technology Transfer				
Thousand Talents Salary	Doctoral Students (low only), Researchers, Workers	$110,000	$170,000	Annual
Thousand Talents Bonus	Doctoral Students (low only), Researchers, Workers	$620,000	$2,400,000	Instance

Source: STPI calculations

We were unable to generate a similar estimate for short-term visitors, foreign-born STEM workers, professors, or post-doctoral fellows. As these individuals have greater access to potentially valuable information and a network of relationships that could be exploited, one might argue that these individuals are more likely to be exploited by the Chinese government or Chinese companies. On the other hand, these individuals are professionals who may not want to endanger their relationships or their ability to continue working in the United States, which may reduce the likelihood that they can be successfully recruited to misappropriate trade secrets or otherwise engage in economic espionage. A priori, we have no reason to assume that these individuals are more or less likely to engage in misappropriation of trade secrets than students. Thus, for the purposes of analysis, we tentatively use the same probability of bad behavior that we assigned to students.

6. Limitations of Our Approach

Many of the benefits and costs associated with allowing foreign STEM talent into the United States cannot be quantified; thus, they are not included in these calculations. For the costs and benefits for which we generate quantitative estimates, our estimates are based on a large number of assumptions about parameters for which we have little insight into margins of error. We encourage readers who disagree with our assumptions to perform their own calculations using their preferred alternatives.

By design, the framework is relatively simple. For instance, we have deliberately limited the number of limbs on our event trees. While simple event trees are easier to understand, they may gloss over subtleties. Nonetheless, we believe that our framework and estimates are useful for analysts and policy makers to understand the high-level trade-offs associated with this complex issue.

B. Expected Benefits or Losses from Foreign STEM Talent in the United States

1. Short-term Visitor

Professors, visitors, STEM employees of businesses, and other STEM talent visit the United States for relatively short periods of time to attend academic conferences, meet customers and suppliers, tour laboratory facilities, meet in person with U.S. colleagues, or combinations of the above. For this category of STEM talent, we assume the main quantifiable benefit to the United States is expenditures on travel, which we estimate as on average $3,100 per trip, excluding airfare.

As the purpose of many of these trips is to learn by engaging with colleagues, attending academic conferences and trade shows, or touring facilities, information is exchanged. In many cases, information flows both ways. Although the transfers of knowledge are a component of ITT, it is not clear whether the United States suffers net economic gains or losses from these flows of information.

Figure 4 shows the event tree for these short-term visitors. The probability that a short-term visitor stays in the United States for a second time step is zero. A visitor who is an NTC may successfully misappropriate U.S. trade secrets during a visit. According to the CSIS data, cases where trade secrets have been misappropriated by an NTC on a short trip are rare. We assign the cost of misappropriation of trade secrets that these instances might impose on the United States as $420,000, our low estimate. We opt not to use the higher value of $57.5 million for misappropriated trade secrets in our expected value calculation because it seems highly unlikely that a visitor could acquire such a valuable asset on a short trip to the United States.

Using the above values and assuming that a full 0.1 percent of visitors are each able to successfully misappropriate $420,000 of trade secrets, we calculate the expected loss per visitor as $420. Subtracting the expected loss from the average benefit of $3,100 that we ascribe to each visitor yields a net expected value per visitor as $2,680. This expected value is positive and thus these visitors are a net benefit to the United States. The expected value may go negative if the probability of being an NTC that successfully misappropriates a trade secret is 0.7 percent—a factor 7 times higher than Evanina's estimate. In short, we find travel expenditures by short-term foreign visitors substantially exceed probable expected losses associated with the misappropriation of trade secrets by an NTC on a short trip to the United States.

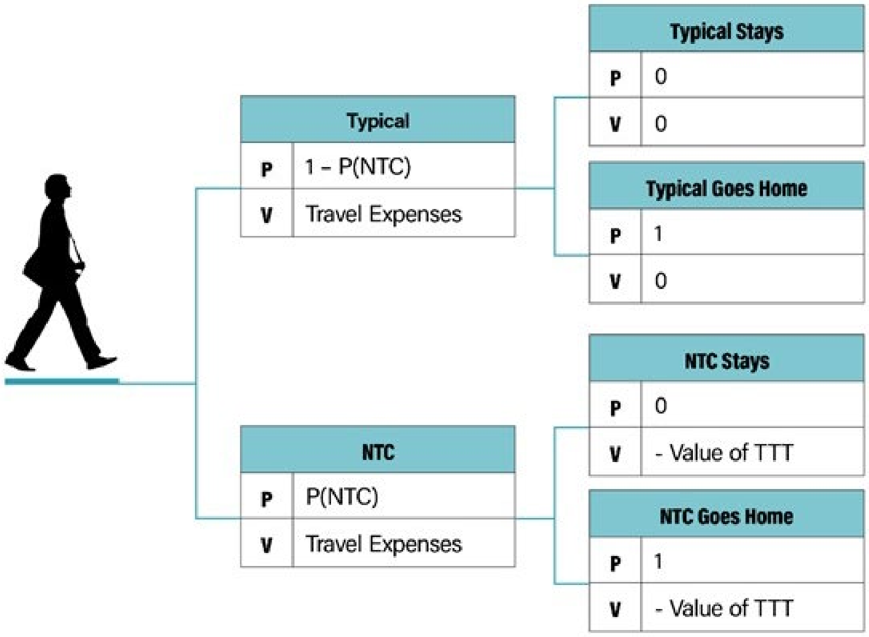

Figure 4. Event Tree for Short-Term Visitors

2. Foreign-born STEM Workers

Foreign STEM talent may enter and work in the United States under a variety of different visa and residency statuses. These workers contribute to the U.S. economy through their labor and their contributions to U.S. innovation. We use the value-added they provide to the U.S. economy as reflected in their compensation to measure the benefit they provide to the U.S. economy. In 2019, average total compensation for STEM workers was $139,605 a year. The main quantifiable potential costs are related to misappropriation of trade secrets while they are in the United States and the value of ITT if they return to their country.

The event tree for foreign-born STEM workers is shown in Figure 5. We consider two time steps. In the first time step, the worker has entered the United States and begun employment. We assign the length of this time step to be 3 years, consistent with the duration of an H-1B visa. While here, typical and NTC individuals produce value for the U.S. economy of $139,605 per year or a cumulative $418,814 over the 3 years. The NTC is assumed to successfully misappropriate one trade secret during this time, which we value at between $0.42 million and $52.5 million per instance.

In the next time step, either the individual manages to stay in the United States, e.g., by his or her employer successfully extending his or her H-1B visa, or the individual leaves the United States, possibly returning to the home country. We do not have a firm estimate for the probability that a foreign-trained worker stays in the United States; thus, we use the estimated probabilities of stay for Chinese citizens who received their doctorate from a U.S. university (83 to 90 percent). We believe this is a reasonable assumption because both U.S.-trained and foreign-trained STEM talent work similar jobs on similar visas. The main qualitative difference is that U.S.-trained talent may be more likely to have deeper connections to the United States, potentially boosting the desire to remain here compared to others who have recently come to the United States for work. For those who stay, the benefits and costs are equivalent to the previous time step, i.e., an NTC may steal more trade secrets, potentially costing the United States up to $115 million over the course of his or her stay. Individuals who leave the United States will transfer the intangible technology that they have acquired. We use estimates of the Chinese government's willingness to pay for this intangible technology for the low and high values shown in Table 35.

The expected values associated with foreign-born STEM workers in the United States are shown in Table 36 for all combinations of potential costs to the United States and potential probabilities that the workers stay in the country. Appendix D provides a fully traceable example of one such calculation from Table 36. The expected values range from approximately $160,000 to $700,000 per individual; they are always positive. For a given combination of misappropriation of trade secrets and ITT values, increasing the probability of stay from 83 percent to 90 percent increases the expected value by approximately $100,000 per person or more.

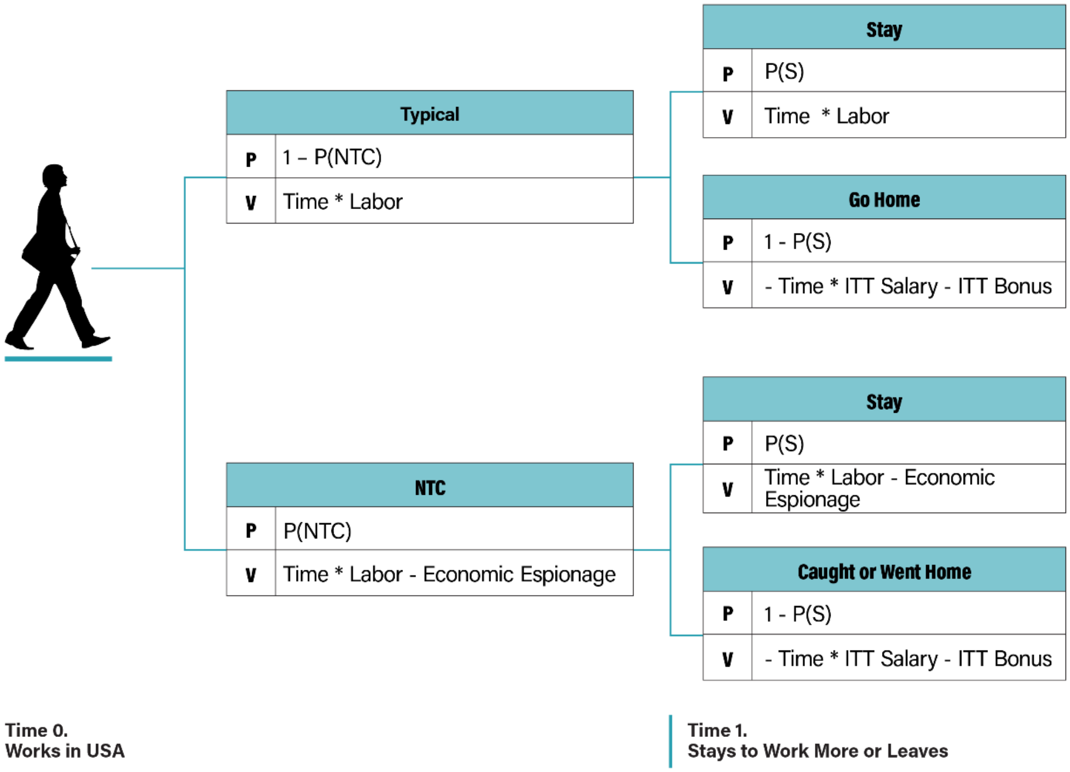

Figure 5. Event Tree for Foreign-born STEM Workers

The table also shows the probability of being a non-traditional collector or otherwise engaging in bad behavior for which the expected value is zero—the costs and benefits break even. Assuming low values for misappropriated trade secrets ($420,000 per instance), 42 percent or more of all foreign-born STEM workers would need to be engaging in the misappropriation of trade secrets for the United States to suffer a net cost from the presence of foreign-born STEM workers in this country. For the high value for misappropriated trade secrets ($57.5 million per instance), more than 0.3 percent of individuals would need to *successfully* steal a trade secret *every year* for the United States to suffer a net loss. This is three time higher than our tentatively used value of 0.1 percent.

Table 36. Expected Values for Foreign-born STEM Workers in the United States and the Probabilities of Being an NTC That Make Expected Values Break Even

Misappropriated Trade Secrets	Value ITT	P(S)	Expected Value	Breakeven P(NTC)
Low	Low	Low	$604,162	79%
		High	$699,950	89%
	High	Low	$270,963	35%
		High	$503,951	63%

Misappropriated Trade Secrets	Value ITT	P(S)	Expected Value	Breakeven P(NTC)
High	Low	Low	$499,706	0.57%
		High	$591,498	0.64%
	High	Low	$166,506	0.26%
		High	$395,499	0.46%

3. Post-Doctoral Fellows and Visiting Researchers

Technically, this is a subset of the foreign-born STEM talent workforce. Consequently, we use the same average annual compensation to calculate benefits from this group. The only difference between this category of STEM talent and other members of the foreign-born STEM workforce is that they are less likely to be able to successfully misappropriate trade secrets because they do not work for U.S. companies. Because they are not employed in companies, the potential value of the intangible technology that they are able to transfer is also likely to be less. In other words, compared to foreign-born STEM talent who work for U.S. companies, the upside for post-doctoral fellows and visiting researchers is about the same but the downside is less. We do not provide numbers for this category because the expected value will be positive under the same assumptions as our analysis for other foreign-born STEM workers.

4. Doctoral Students

Students pursuing a doctorate in the United States on average live, work, and conduct research in the United States for a period of about 6 years. After foreign students finish their degrees, they may apply for optional practical training (OPT), which allows them to work in the United States for up to 3 years. Most individuals who receive their doctorates in the United States remain for OPT and often longer, benefiting the U.S. economy through their work.

Figure 6 shows the event tree for a person who comes to the United States as a doctoral student. In the first time step, the individual is either an NTC or not. In both cases, the individual conducts his or her research and receives a doctorate. During the course of their research, we assume doctoral students contribute to U.S. innovation. We capture the value-added from their research through their contributions to increases in U.S. TFP. We estimate this value based on average annual increases in total factor productivity of $12,225 to $13,568 per year for each student (Table 35). We assume that this value is a consequence of their studies in the United States; foreign doctoral students are assumed not to bring substantial ITT with them when they enter the United States. The doctoral student is assumed to receive a fellowship and stipend from the university to cover room, board, and tuition. We do not consider this a salary, so we do not consider it an economic benefit to the United States, especially as the source of these funds is often U.S. Government grants.

For simplicity, we use only the low value for the increase in TFP as the annual economic value of the doctoral research.

We assume that the NTC misappropriates and exports a trade secret every year. Because doctoral students have much less access to corporate trade secrets, we assume that the value of the trade secrets NTCs misappropriate is at the low end of our spectrum: $420,000 per secret.

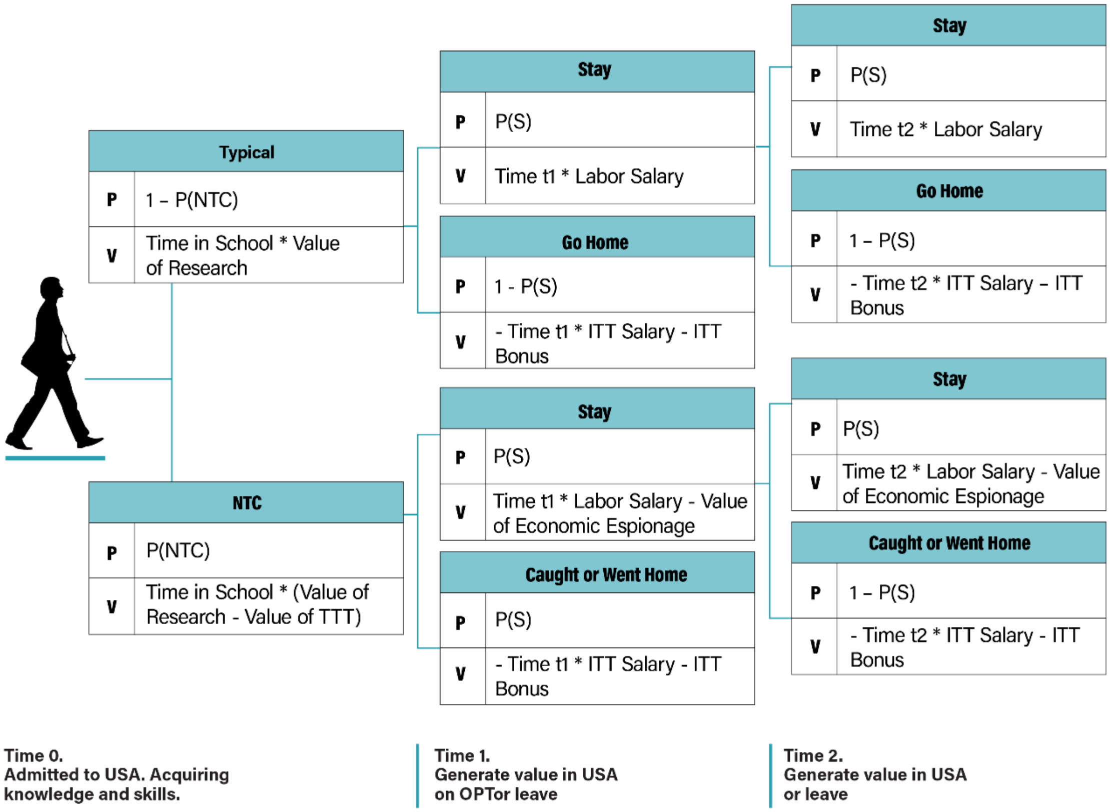

Figure 6. Event Tree for Doctoral Students

After completing his or her degree, the individual may stay in the United States to work, contributing the value of his or her labor to the U.S. economy during this time. We assume that all graduating doctorates stay in the United States at the same rate, have the same annual value of labor, and stay for the maximum OPT duration of 3 years. The NTC who stays continues to misappropriate trade secrets, but because the NTC now works in a company, the value of the trade secret may range from $0.42 to $57.5 million.

If they choose to leave, all doctorates transfer intangible technology to the home country. We estimate the value of this ITT as the value that Chinese talent programs are willing to pay for a highly talented post-doctoral fellow to return to mainland China—the low values in Table 35. This figure is an overestimate because at this point in time, the individual has not completed a post-doctoral fellowship or had equivalent experience.

In the final time step, individuals who complete their OPT in the United States may try to remain in the United States or leave. The benefits and costs to the United States are the same as in the previous time step, with the exception that the intangible technology that the individual is now capable of transferring is likely to be more valuable. We use the compensation that the Chinese government is willing to pay through the talent programs for a post-doctoral fellow as the value of the individual's ITT. This time step lasts 3 years, the initial duration of an H-1B visa that an individual may use to stay in the United States for work.

Table 37. Expected Values for Foreign Doctoral Students in the United States and the Probabilities That Make Expected Values Break Even

Value of Misappropriated Trade Secrets During doctorate	Value of Misappropriated Trade Secrets During Work	P(S)	Expected Value	Breakeven P(NTC)
Low	Low	Low	$413,305	65%
		High	$608,305	85%
	High	Low	$326,606	47%
		High	$510,699	62%
High	Low	Low	$410,785	13%
		High	$605,785	19%
	High	Low	$324,086	0.46%
		High	$508,179	0.60%

Note: For all scenarios, we assume low values of ITT because, even after a 3-year work period in the United States, the individuals are too junior to earn the higher levels of ITT.

In the latter two time steps, we use the same probabilities of stay for typical individuals and NTCs: 83 and 90 percent. The expected values associated with this category of STEM talent are shown in Table 37. The expected values are always positive and range from approximately $320,000 to over $600,000 per individual, similar to our analysis of STEM workers. In the worst cases, the probabilities of being an NTC for which the expected value breaks even are a factor of 4 to 6 times higher than our 0.1 percent. We find these breakeven probabilities highly unlikely. The longer the individual stays and works in the United States, the higher the net benefit. In short, because many Chinese doctorates stay in the United States, net benefits greatly outweigh expected losses.

5. Bachelor's and Master's Students

We assume that foreign bachelor's and master's students would be ineffective as NTCs due to their lack of knowledge and connections to companies. Consequently, we assume economic costs from the misappropriation of U.S. trade secrets are zero for this group. As with the other categories, we were unable to estimate losses to the United States from ITT, although we note it is substantially less than for the other categories, as these individuals are more focused on coursework and are not in a good position to acquire intangible technologies. All foreign students are assumed to pay tuition, room, and board because they usually do not get U.S. scholarships. Master's students are assumed to stay 2 years and bachelor's students 4. Table 38 shows our calculations of net benefits for foreign bachelor's and master's students. As can be seen, net benefits are always positive. Figure 7 shows the event tree.

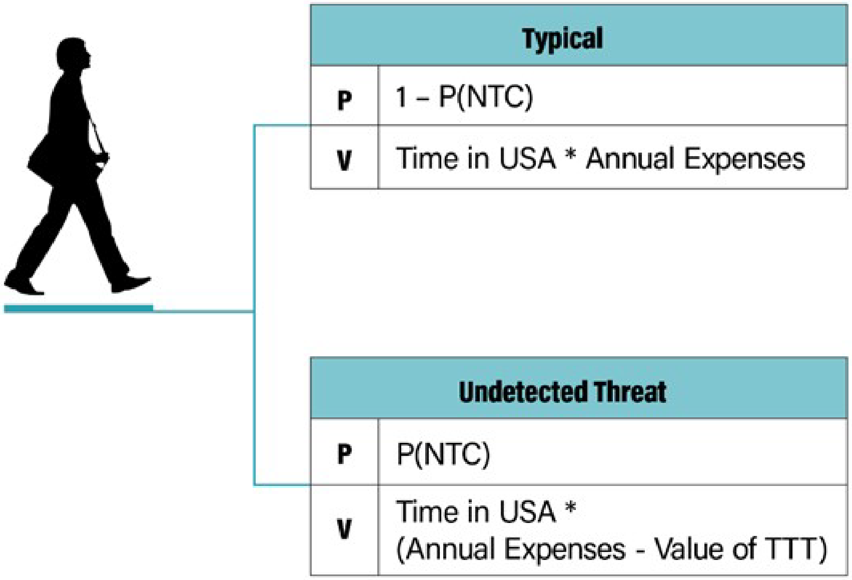

Figure 7. Event Tree for Bachelor's and Master's Students

Table 38. Expected Economic Benefits to the United States from Foreign Bachelor's and Master's Students

Student	Years	Room, Board and Tuition—Low	Cumulative Expenditures—Low	Room, Board and Tuition—High	Cumulative Expenditures—High
Bachelor's	4	$37,390	$149,560	$48,290	$193,160
Master's	2	$19,050	$38,100	$41,990	$83,980

Source: STPI calculations

Appendix A.
Overview of Select Data Sources on the U.S. STEM Labor Force

The Federal statistical data sources used in this chapter are described briefly in Table A-1 as context on the populations that each includes. Additional context about the data sources is provided when findings from that data source are discussed.

Table A-1. Overview of Data Sources Used

Data Source Name	Federal Agency	Population Described by This Data Source
National Survey of College Graduates (NSCG) (NSF n.d.)	National Center for Science and Engineering Statistics (NCSES)	The NSCG surveys a sample of ~150,000 individuals who are living in the United States (including Puerto Rico and other U.S. territories) during the survey reference week, have at least a bachelor's degree, and are younger than 76 years old (using the American Community Survey as a sample frame). The NSCG uses a rotating panel design that includes both new and returning respondents to track individuals longitudinally over time. The NSCG includes an oversampling of recent graduates. The NSCG, unlike SED, includes individuals educated outside of the United States who are now living in the United States.
Survey of Earned Doctorates (SED) (NSF n.d. a)	NCSES	The SED is a census of all individuals who received a research doctorate from a U.S. doctorate-granting institution in the prior year. The SED includes individuals across all degree fields.
Survey of Doctoral Recipients (SDR) (NSF n.d. b)	NCSES	The SDR surveys a sample of ~120,000 individuals who have earned a science, engineering, or health research doctoral degree from a U.S. academic institution and are less than 76 years of age (using the SED as a sample frame). The SDR uses a rotating panel design that includes new and returning respondents to track individuals longitudinally over time. Changes to the SDR in 2010 and 2015 have enabled tracking of individuals residing outside of the United States.
American Community Survey (ACS) (U.S. Census Bureau 2020)	Census Bureau	The ACS is an annual survey of a sample of ~3.5 million households in the United States, using the Census Bureau's Master Address File as a sample frame. Therefore, the ACS population from which its samples are drawn includes all housing units (occupied or vacant), all people in households, and almost all people in group quarters (such as college dorms, prisons, nursing homes, etc.)

Data Source Name	Federal Agency	Population Described by This Data Source
Integrated Postsecondary Education Data System (IPEDS) (IIE n.d.)	National Center for Education Statistics (NCES)	IPEDS is a census of all Title IV Eligible Postsecondary Institutions, meaning its respondents include every college, university, and technical and vocational institution that participates in these Federal student financial aid programs.
Occupational Employment Wage Statistics (OEWS) (BLS n.d. b)	Bureau of Labor Statistics (BLS)	The OEWS survey is based on a sample of business establishments drawn from the Quarterly Census of Employment and Wages (QCEW), the database of businesses reporting to the state unemployment insurance programs. The sample is designed to be statistically representative by industry and geographic area. Larger employers are included in the OEWS sample with virtual certainty; a probability sample is taken of smaller employers. Each set of OEWS estimates is produced by combining six semiannual survey panels collected over a 3-year period. Each survey panel contains approximately 180,000 to 200,000 establishments, for a total 3-year sample size of 1.2 million business establishments.
Current Population Survey (U.S. Census Bureau n.d.)	BLS	The CPS is a monthly survey of ~60,000 households in the United States, selected from the Census Bureau's Master Address File as a sample frame. The CPS sample includes the civilian, non-institutionalized population over 16 years of age.

Appendix B.
Data Used to Calculate Increases in TFP Tied to Foreign STEM Talent

Table B-1. Calculations of Increases in GDP Due to Contributions of Foreign-born STEM Workers to TFP (billions of 2019 dollars)

Year	GDP	Change in GDP	Index of TFP	Increase in TFP	Change in GDP Due to Increase in TFP	Change in GDP Due to Foreign STEM Talent
2000	$14,742	$584	88.9	1.6%	$237	$67
2001	$14,889	$147	89.3	0.5%	$74	$21
2002	$15,148	$259	91.1	2.0%	$310	$87
2003	$15,581	$433	93.4	2.5%	$386	$109
2004	$16,173	$592	95.6	2.3%	$373	$105
2005	$16,742	$568	97.0	1.5%	$250	$70
2006	$17,220	$478	97.4	0.4%	$77	$22
2007	$17,543	$323	97.9	0.5%	$81	$23
2008	$17,519	-$24	96.8	-1.1%	-$196	-$55
2009	$17,074	-$444	97.1	0.3%	$53	$15
2010	$17,512	$438	99.7	2.7%	$464	$131
2011	$17,784	$272	99.4	-0.2%	-$43	-$12
2012	$18,184	$400	100.0	0.6%	$108	$30
2013	$18,519	$335	100.4	0.4%	$70	$20
2014	$18,986	$468	100.9	0.5%	$94	$26
2015	$19,570	$584	102.0	1.1%	$221	$62
2016	$19,905	$335	101.7	-0.3%	-$64	-$18
2017	$20,369	$464	102.2	0.5%	$106	$30
2018	$20,980	$610	103.2	1.0%	$209	$59
2019	$21,433	$453	104.0	0.7%	$154	$43
Average					**$148**	**$42**

Appendix C.
STPI List of R&D-Intensive Industries

Table C-1. STPI List of R&D-Intensive Industries

Number	Industry
	Machinery
96	Semiconductor machinery manufacturing
97	Other industrial machinery manufacturing
98	Optical instrument and lens manufacturing
99	Photographic and photocopying equipment manufacturing
100	Other commercial and service industry machinery manufacturing
106	Machine tool manufacturing
107	Cutting and machine tool accessory, rolling mill, and other metalworking machinery manufacturing
108	Turbine and turbine generator set units manufacturing
	Computer and Electronic Products
120	Electronic computer manufacturing
121	Computer storage device manufacturing
122	Computer terminals and other computer peripheral equipment manufacturing
123	Telephone apparatus manufacturing
124	Broadcast and wireless communications equipment
125	Other communications equipment manufacturing
126	Semiconductor and related device manufacturing
127	Printed circuit assembly (electronic assembly) manufacturing
128	Other electronic component manufacturing
	Electrical equipment, appliances, and components
129	Electromedical and electrotherapeutic apparatus manufacturing
130	Search, detection, and navigation instruments manufacturing
131	Automatic environmental control manufacturing
132	Industrial process variable instruments manufacturing
133	Totalizing fluid meter and counting device manufacturing
134	Electricity and signal testing instruments manufacturing
135	Analytical laboratory instrument manufacturing
136	Irradiation apparatus manufacturing
139	Manufacturing and reproducing magnetic and optical media
150	Relay and industrial control manufacturing

Number	Industry
151	Storage battery manufacturing
152	Primary battery manufacturing
155	Carbon and graphite product manufacturing
156	All other miscellaneous electrical equipment and component manufacturing
	Other transportation equipment
171	Aircraft manufacturing
172	Aircraft engine and engine parts manufacturing
173	Other aircraft parts and auxiliary equipment manufacturing
174	Guided missile and space vehicle manufacturing
175	Propulsion units and parts for space vehicles and guided missiles
	Miscellaneous manufacturing
190	Surgical and medical instrument manufacturing
191	Surgical appliance and supplies manufacturing
192	Dental equipment and supplies manufacturing
193	Ophthalmic goods manufacturing
194	Dental laboratories
	Chemical products
260	Pharmaceutical preparation manufacturing
261	In-vitro diagnostic substance manufacturing
262	Biological product (except diagnostic) manufacturing
264	Pesticide and other agricultural chemical manufacturing
	Data processing, internet publishing, and other information services
317	Software publishers
325	Data processing, hosting, and related services
326	Internet publishing and broadcasting and Web search portals
	Professional, scientific, and technical services
344	Custom computer programming services
345	Computer systems design services
351	Scientific research and development services
356	All other miscellaneous professional, scientific, and technical services

Appendix D.
Example of Expected Value Calculation

All expected value calculations are performed in a Microsoft Excel workbook. In this appendix, we discuss a single expected calculation from the workbook in depth for the reader to fully understand the process. Specifically, we calculate the expected value of a foreign-born STEM worker, assuming a high value of TTT ($57.5 million), a low value of ITT ($110,000 annual salary and a one-time bonus of $620,000), and a low probability of staying in the United States (83 percent). This corresponds to the fifth row from Table 36. For convenience, we reproduce the associated event tree (Figure 5) here. The event tree uses two time periods, which we assign a length of 3 years each. The STEM worker's labor in the United States is valued at $139,605 per year. All of the monetary values used are drawn from Table 35.

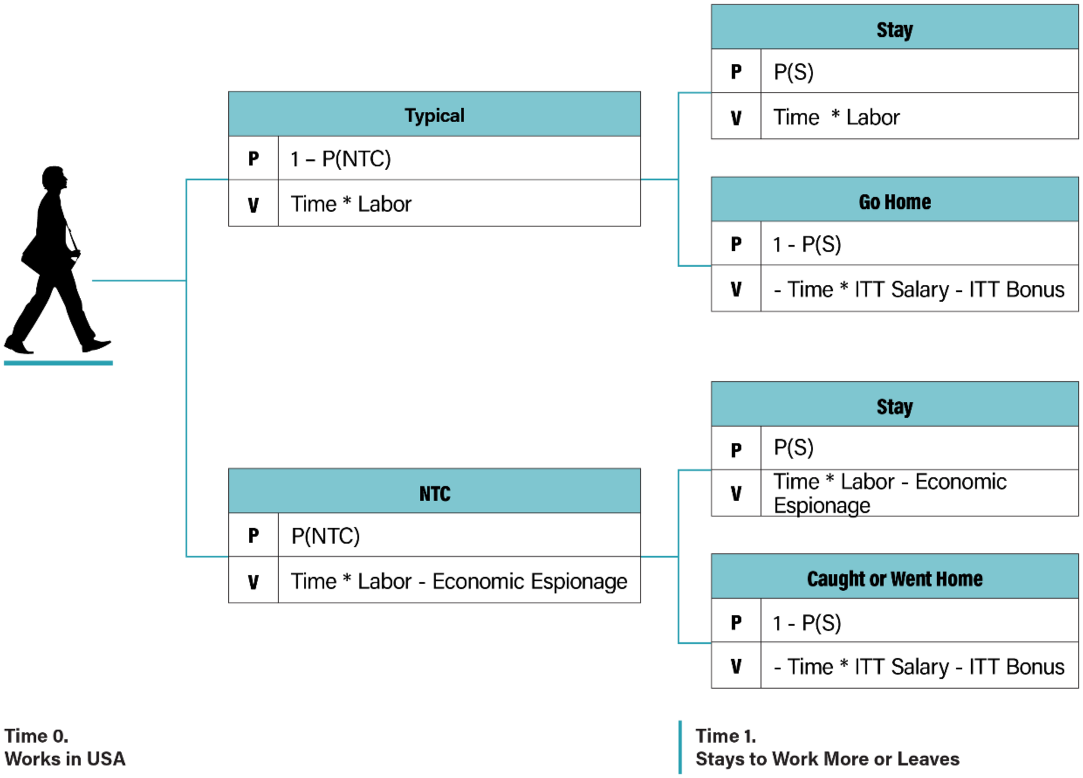

Figure D-1. Event Tree for Foreign-born STEM Workers Reproduced from Chapter 6

Table D-1 shows the variables used, populated with the values discussed previously. Each variable has a prefix that associates it with the category of STEM talent to which it applies. For STEM workers, we use the prefix "corp_", short for "corporate", which is used to denote foreign-born STEM workers. The probability of stay (corp_prob_stay) and the probability of being a non-traditional collector (corp_prob_ntc) are expressed as probabilities in the range of zero to one—not as a percentage.

Table D-1. Variable Names and Associated Values for Sample Expected Value Calculation for Foreign-born STEM Workers

Variable	Value	Units
corp_prob_ntc	.0001	[0-1]
corp_prob_stay	0.83	[0-1]
corp_value_econ_espionage	$57,500,500	Dollars per instance
corp_value_itt_salary	$110,000	Dollars per year
corp_value_itt_bonus	$620,000	Dollars per instance
corp_annual_labor_value	$139,605	Dollars per year
corp_time_0	3	Years
corp_time_t1	3	Years

The limbs of the event tree in D-1 trace out four scenarios. The first two are where a typical worker comes to the United States and stays for a second work period (Typical Stay) or goes home (Typical Go Home). Alternatively, an NTC may come to the United States and stay for a second work period (NTC Stay) or go home (NTC Go Home). For the purposes of analysis, the NTC is assumed to commit economic espionage each time period they are in the United States. In other words, the NTC Stay scenario includes the costs associated with two acts of economic espionage. The value of each scenario is computed by summing the values of its associated limbs. Likewise, the probability of each scenario is the product of the probabilities of the associated limbs. The expected value of a scenario is the product of its probability and value. The expected value of the full event tree is the sum of the expected values of the scenarios. The calculation is shown in Table D-2.

Table D-2. Calculating Values and Probabilities of Each Tree Limb and Total Expected Value

Probability	Value	Limb	Name of Scenario	Expected Value
Time 0. Works in the United States				
0.999	$418,815	Typical [a]		
0.001	-$57,081,185	NTC [b]		
Time 1. Typical Limbs: Stays or Leaves the United States				
0.83	$418,815	Stay [c]		
0.17	-$950,000	Go Home [d]		
Time 1. NTC Limbs: Stays or Leaves the United States				
0.83	-$57,081,185	Stay [e]		
0.17	-$950,000	Go Home [f]		
Total				
0.8292	$827,630		Typical Stay [g]	$694,538
0.1698	-$531,185		Typical Goes Home [h]	-$90,211
0.0008	-$114,162,370		NTC Stays [i]	-$94,755
0.0002	-$58,031,185		NTC Goes Home [j]	-$9,865
1.0			Total Expected Value	$499,706

a. Probability = 1 - corp_prob_ntc; Value = corp_time_t0 * corp_value_annual_labor

b. Probability = corp_prob_ntc; Value = corp_time_t0 * corp_value_annual_labor - corp_value_econ_espionage

c. Probability = corp_prob_stay; Value = corp_time_t1 * corp_value_annual_labor

d. Probability = 1- corp_prob_stay; Value = -(corp_time_t1 * corp_value_ITT_salary + corp_value_ITT_bonus)

e. Probability = corp_prob_stay; Value = corp_time_t1 * corp_value_annual_labor - corp_value_econ_espionage

f. Probability = 1- corp_prob_stay; Value = -(corp_time_t1*corp_value_ITT_salary + corp_value_ITT_bonus)

g. Probability = 0.999 * 0.83; Value = $418,815 + $418,815

h. Probability = 0.999 * 0.17; Value = $418,815 - $950,000

i. Probability = 0.001 * 0.83; Value = -$57,081,185 - $57,081,185

j. Probability = 0.001 * 0.17; Value = -$57,081,185 - $950,000

Table of Tables

Glossary of Terms

Terms Related to Foreign Talent

Foreign Born – Individuals born outside of the United States. Foreign-born individuals may be U.S. citizens (native or naturalized), as well as permanent or temporary residents of the United States.

Foreign STEM Talent – Generic term used to describe either foreign-born or non-U.S. citizens in the United States working STEM jobs.

Immigrant – An individual born with non-U.S. citizenship that is now a permanent resident or citizen of the United States.

Non-Immigrant – An individual born with non-U.S. citizenship that is currently a temporary resident of the United States.

Non-U.S. Citizen – Individuals who are not citizens of the United States. Non-U.S. citizens include both permanent and temporary visa holders.

U.S. Foreign-born STEM Workforce – Foreign-born individuals employed in STEM jobs in the United States.

Terms Related to the STEM Workforce

There is no single definition for what constitutes the STEM workforce or a STEM degree field or STEM occupation. Most Federal agencies use a definition that suits their particular needs. Because of these different definitions, some of the data we reference throughout the report may classify STEM degree fields or occupations in different ways. We are careful to indicate which definition of STEM is being used in each instance.

S&E Occupation and S&E Degree Field – These are the terms traditionally used by NSB/NSF to describe a STEM occupation or degree field (NSB/NSF 2019a; NSB/NSF 2020). In this report, where we use S&E, it is because we used data that originated from NSB/NSF or NCSES sources that used this designation.

STEM Degree Field – All definitions of STEM degree fields include computer science, mathematics, biological, agricultural, and environmental and physical sciences, and engineering. In most of this report, we use the NSB/NSF definition that also includes social sciences, as well as health and medical science degree fields at the doctoral level because of their research focus (NSB 2020). The DHS STEM Designated Degree Program list is among the broadest, including nearly all the degree fields that other lists consider both STEM and STEM-related (DHS n.d.).

STEM-Related Degree Field – Health and medical science degrees are typically considered STEM-related degree fields.

STEM Occupation – All definitions of STEM occupation include computer scientists, mathematicians, biological, agricultural, and environmental life and physical scientists, and engineers. NSB/NSF also include social scientists and post-secondary STEM teachers in STEM occupations (NSF 2019a).

STEM-Related Occupation – Health and medical occupations and STEM managers and STEM technicians/technologists are typically considered STEM-related occupations. BLS also considers social scientists to be STEM-related occupations (BLS n.d. a.).

STEM Workforce – We use the narrow definition of a STEM or S&E workforce traditionally used by the NSB/NSF that includes individuals with a bachelor's degree in the following occupational groups: (1) computer and mathematics scientists; (2) biological, agricultural, and environmental life scientists; (3) physical scientists; (4) social scientists; and (5) engineers. When an alternate definition is used in this report, we make note of that difference in the text.

Other Terms

Employed – A person who has a job is employed.

Labor Force – The labor force is made up of all employed and unemployed individuals.

Not in Labor Force – Individuals not in the labor force are those who are not employed or unemployed. These individuals are jobless, but are not looking for a job or available for work. These individuals include those in school, the disabled, those engaged at home in raising children and managing their households, the retired, and other individuals not engaged in paid work or looking for paid work.

Unemployed – A person who is jobless, looking for a job, and available for work is unemployed.

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Abbreviations

ACS	American Community Survey
BEA	U.S. Bureau of Economic Analysis
BLS	Bureau of Labor Statistics
BSA	Business Software Alliance
CBP	U.S. Customs and Border Protection
CEO	chief executive officer
CIP	classification of instructional programs
CSET	Center for Security and Emerging Technology
CSIS	Center for Strategic and International Studies
DHS	Department of Homeland Security
GDP	Gross Domestic Product
IDA	Institute for Defense Analyses
IP	intellectual property
IPEDS	Integrated Postsecondary Education Data System
IPR	intellectual property rights
ITT	intangible technology transfer
MERICS	Mercatur Institute for China Studies
NCES	National Center for Education Statistics
NCSES	National Center for Science and Engineering Statistics
NSB	National Science Board
NSC	National Security Council
NSF	National Science Foundation
NTC	non-traditional collector
OECD	Organisation of Economic Co-operation and Development
OEWS	Occupational Employment and Wage Statistics
OPT	optional practical training
OSTP	Office of Science and Technology Policy
QCEW	Quarterly Census of Employment and Wages
R&D	research and development
RMB	renminbi
S&E	science and engineering
SDR	Survey of Doctoral Recipients
SED	Survey of Earned Doctorates
SEH	science, engineering, and health
SESTAT	Scientists and Engineers Statistical Data System
SOC	standard occupation classification
STEM	science, technology, engineering, and mathematics
STPI	Science and Technology Policy Institute
TBSI	Tsinghua−Berkeley Shenzhen Institute

TFP	total factor productivity
TTT	tangible technology transfer
USITC	United States International Trade Commission

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14. ABSTRACT

This paper provides quantitative estimates of the economic benefits and costs to the United States of foreign STEM talent who visit, study or work in this country. It is designed to assist in the formulation of effective policies to reduce economic losses associated with the misappropriation of U.S. trade secrets to competitor countries, in particular China, while preserving the benefits of foreign STEM talent to the United States. The study finds that the United States gains substantial economic benefits from foreign STEM talent in this country. In 2019, in aggregate, the foreign-born STEM workforce contributed $367 billion to $409 billion in labor value-added, 1.7 to 1.9 percent of U.S. GDP. Foreign-born entrepreneurs have helped found U.S. companies in R&D-intensive industries; the value-added from these companies is estimated to range from $260 billion to $394 billion, or 1.2 to 1.8 percent of GDP. The primary economic costs to the United States from foreign STEM talent are misappropriation of trade secrets and the transfer of intangible technologies as foreign-born individuals who have worked or studied in the United States return to their home countries and use that knowledge to contribute to the development of new industries that compete with U.S. industries. On a net basis, foreign-born STEM workers are economically beneficial to the United States: net benefits range run from $200,000 to $700,000 per individual over a three-year period on a net basis. Post-doctoral fellows, visiting researchers, and graduating PhD students also benefit the United States economically on net basis.

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