Foreign Science and Engineering Doctoral Attainment at American Universities

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at George Mason University

By

Robert V. Hamilton
Master of Arts
University of California San Diego, 1991
Bachelor of Arts
University of California Berkeley, 1982

Director: Wayne D. Perry, Professor
School of Public Policy

Fall Semester 2009
George Mason University
Fairfax, VA

DEDICATION

This is dedicated to my parents and to my grandmother Mabel Claire Hamilton, who taught second grade in Edmond, Oklahoma for over 30 years.

ACKNOWLEDGEMENTS

I would like to thank my committee chair Dr. Wayne D. Perry for his mentoring and support over the entire course of this dissertation. I would also like to thank Dr. Connie McNeely who along with Dr. Perry from George Mason University's School of Public Policy encouraged this research on highly-skilled migration and education even before it attained its current high level of interest in public policy circles. Additional thanks go to Dr. Beverly Shaklee, the Director of George Mason University's Center for International Education, for her help and valuable insights into the dynamics of international education at American universities. Thanks also to Dr. James Hosek, the Director of the RAND Forces and Resources Policy Center, for his efforts and constructive comments as the External Reader for this dissertation. Many thanks also to Dr. Erich Franz Stocker of NASA for his initial encouragement and subsequent support in allowing me to balance work and doctoral study. Finally, thanks to Yukari, Robbie and Mark Hamilton for all their love. This was truly a family effort.

TABLE OF CONTENTS

LIST OF TABLES

ABSTRACT

FOREIGN SCIENCE AND ENGINEERING DOCTORAL ATTAINMENT AT AMERICAN UNVERSITIES

Robert V. Hamilton, PhD

George Mason University, 2009

Dissertation Director: Wayne D. Perry, Professor

This dissertation analyzes the nearly 100,000 foreign students who attained science and engineering (S&E) doctorates in the five fields of physical sciences, life sciences, engineering, mathematics and computer sciences, and social and behavioral sciences at American universities from 1994 to 2005. Two models are presented. In the first model controlling for population, multivariate regression results testing for whether foreign students from higher or lower income nations (181 nations) tended to attain S&E doctorates showed that certain S&E fields tended to be represented by students from higher income nations early in the time period (e.g. 1994 to 1999) but the national income variable explaining foreign S&E doctoral attainment was not statistically significant in four of the fields after the year 2000.

Four nations, China, India, South Korea and Taiwan stand out due to their large S&E doctoral student presence at American universities, but virtually all growth in foreign doctoral attainment in four of the S&E fields from 1994 to 2005 came from Chinese students, and this growth was most pronounced after the year 2001. In short, whereas the foreign student populations from South Korea and Taiwan were the outliers in 1994 and as such skewed testing results, they had largely been displaced in 2005 by the increased presence of Chinese students. From the US public policy perspective, to the extent that growth in foreign S&E doctoral attainment is an issue to include its related costs and benefits, the appropriate policy focus should shift more specifically towards the growth in Chinese S&E doctoral attainment. Further, with the exception of China and India, foreign doctoral students from the lowest income nations of the world in all five S&E fields were greatly under represented on American campuses from 1994 to 2005.

Testing results from the second model complement the findings in the first model. Whereas the first model tested for the effects of national income on foreign S&E doctoral attainment, the second model tested for changes in foreign S&E doctoral attainment over the time period 1994 to 2005. Specifically, testing results for the second model indicated that changes in S&E doctoral attainment by students from the lower income nations tended to more closely track changes in education-related R&D funding compared to students from higher income nations. These results suggest that to the extent the US government desires to increase foreign doctoral attainment in specific S&E fields, students from lower income nations might have a greater tendency to "chase" education-related R&D dollars in the targeted S&E fields.

Finally, testing results for both models indicate that there was variation between the five S&E fields, and that highly-skilled migration patterns in certain S&E fields changed relatively quickly during the time period 1994 to 2005. These results suggest that foreign S&E doctoral attainment should be disaggregated both temporally and by S&E population in order to adequately measure and understand this phenomenon.

Chapter 1

Introduction

This paper examines foreign student presence in US science and engineering doctoral programs for the time period 1994 to 2005. Science and engineering (S&E) is defined as encompassing the following five fields of study: *physical sciences, life sciences, engineering, mathematics and computer sciences, social and behavioral sciences*. Foreign S&E doctorates are defined as those S&E doctorates attained at American universities by non-US citizens in a temporary resident (non-immigrant/non-green card) visa status. Research interest in this population is merited because of its increased numbers compared to US citizen and permanent resident S&E doctorates. In this study, foreign S&E doctoral attainment at American universities is treated as a case of highly-skilled migration, a subject of continuing public policy interest (Hamilton and Perry 2008, Hart 2006). "To study abroad is to migrate" (Myers 1972 p. 44), and in 1980 there was a total 2,842 S&E doctorates attained by foreign students at American universities, comprising 16 percent of total S&E doctorates attained. By 2005, this number had increased to 11,109, comprising 38 percent of total doctorates attained. Put another way, from 1980 to 2005 the US citizen and permanent resident share of S&E doctorates at American universities decreased from 84 percent to 62 percent. Table 1 shows the representation of foreign S&E doctorates at American universities compared to US citizen and permanent residents in 2005 by S&E field. Two S&E fields showed majority representation by foreign students: the foreign student share of engineering doctorates at American universities in 2005 was 61 percent, and the foreign student share for mathematics and computer sciences doctorates was 54 percent. Additionally, the foreign student share of physical sciences doctorates was 43 percent. US citizens and permanent residents dominated two S&E fields, where the foreign student presence in life sciences doctorates was only 28 percent, and the share for social and behavioral sciences doctorates was only 21 percent (NSF/NIH/USED/HEH/USDA/NASA 2009).

From another perspective, Table 1 shows that almost two-thirds of US citizen and permanent resident S&E doctorates in 2005 were attained in only two fields: life sciences (6,442) and social and behavioral sciences (5,278).

<u>Table 1</u> S&E Doctorates Attained at American Universities, 2005

Field	Foreign Doctorates Totals	US Citizen Doctorate Totals	Total	Percentage Foreign Share of Total
Physical Sciences	1,847	2,442	4,289	43
Life Sciences	2,496	6,442	8,938	28
Engineering	3,964	2,535	6,499	61
Mathematics and Computer Sciences	1,357	1,168	2,525	54
Social and Behavioral Sciences	1,445	5,278	6,723	21
Totals	11,109	17,865	28,974	38

Source: NSF/NIH/USED/HEH/USDA/NASA (2009)

Of special note here is the variation in the total share of doctorates attained by the foreign student population in 2005 between the five S&E fields. This study will focus on the foreign component of the S&E doctoral population at American universities during the twelve year time period from 1994 to 2005. Foreign doctorates from the five S&E fields will be treated as five separate populations. Is any variation with respect to the type and numbers of doctorates within each of these five S&E populations explained by factors associated with the national origin of these foreign doctorates? Is there any variation between the five S&E fields?

Overview of Foreign S&E Doctoral Attainment: 1978 to 2005

Appendix A provides a longitudinal (temporal) view of foreign S&E doctoral attainment for the five S&E fields. From 1978 to 2005, there were 176,187 S&E doctorates attained by foreign students from 181 nations at American universities. In 1978, there was a total of 2,646 S&E doctorates attained, and by 1990 this number had increased to 7,215. As mentioned, the most recent available data show that in 2005 this number had increased to 11,109. Note that increases in foreign S&E doctoral attainment from 1978 to 2005 vary across the five S&E fields. For example, physical sciences show the smallest factor increase in doctoral count (3.7), from 503 in the year 1978 to 1,847 in the year 2005, while mathematics and computer sciences show the largest factor increase (6.9), from 198 in the year 1978 to 1,357 in the year 2005. Also note that Appendix A shows the varying shares of the total foreign S&E doctorates each year for 1978 to 2005. For example, the share of engineering increased from 30 percent of the S&E total in 1978 to 36 percent in 2005, while the mathematics and computer sciences share increased from 7 percent to 12 percent for the same time period. The share of both physical and life sciences remained fairly steady for this 1978 to 2005 time period, while the share for social and behavioral sciences decreased from 20 percent in 1978 to 13 percent in 2005. In other words, from 1978 to 2005 foreign S&E doctoral attainment became less weighted in the social and behavioral sciences and more weighted towards engineering and mathematics and computer sciences, while the share for physical sciences and life sciences remained fairly constant.

Foreign S&E Doctoral Presence at American Universities: Policy Debate

Highly-skilled migration is a subject of current public policy interest. That is, governments play a key role in foreign S&E doctoral highly-skilled migration to American universities, due to national immigration policies that regulate the cross-border flow of students (Arango 2004, Myers 1972). In this sense, the policy variable to be tested in this research is one of immigration policy, in the form of the foreign S&E doctoral students that the US government allows into the country. Further, current US immigration policy also imposes restrictions upon newly minted foreign S&E doctorates from staying and working in the United States upon degree completion. This policy indicates that foreign S&E doctoral attainment at American universities is not necessarily a simple free market phenomenon, but rather is an endeavor with a potentially high degree of government involvement (Arango 2004) and deserving of study in the public policy context.

There is also a policy debate over the costs and benefits related to highly-skilled migration, and foreign S&E doctoral attainment at American universities is part of this debate. A heightened foreign doctoral presence as shown in Table 1 has been viewed in a variety of policy contexts with respect to US science and technology strength. One view sees the increase in foreign S&E doctorates at American universities as yet another example of the United States attracting the best and brightest from throughout the world (Stephan and Levin 2001, Lerner 1987) where,

"From welcoming 'your tired, your poor, your huddled masses yearning to breathe free,' the United States seems to have moved toward a policy of welcoming the alert, the skilled, and the educated few" (Myers 1972 p. 37).

Proponents of the view that talented foreign students are of net benefit to the United States argue for policies that promote their recruitment, to include government efforts to, "reform immigration policies to create clear pathways to permanent residency and U.S. citizenship for top international students who earn U.S. degrees, as well as outstanding scientists and engineers in the U.S. on exchange or work visas" (AAU 2006). On a related note, there was an expressed concern that more stringent US student visa requirements in the post September 11, 2001 era might be reducing the numbers of qualified foreign students pursuing S&E graduate degrees, leading to a shortage of S&E researchers in the United States (House Science Committee 2004). Studies suggest that nations and regions have benefited from the presence of talented people, thus providing the rationale for governments to promote polices to better attract them (Lucas 1988, Porter 1998, Glaeser 1998, Stephan and Levin 2001). Included is a view that as a, *"creative hub…Universities are amazingly effective talent attractors, and their effect is truly magnetic. By attracting eminent researchers and scientists, universities in turn attract graduate students, generate spin-off companies and encourage other companies to locate nearby in a cycle of self-reinforcing growth"* (Florida 2002, pp. 291-92).

However, another long-held view is that highly-skilled migration, particularly from lower income nations, may lead to wider gaps between rich and poor nations and retardation of economic development (Myers 1972). More recently, highly-skilled migration has been characterized in potential win-win terms, meaning not brain drain but "brain gain," with a focus on optimizing benefits to developed nations while mitigating costs to developing ones[1] (Hart 2006). An example of the win-win aspect of foreign scientists and engineers educated in the United States is their role in creating production networks benefiting both their home nations and the nations in which they study (Saxenian 2002). About 70 percent of foreign S&E doctorates have stayed and contributed to the US science and technology base upon S&E doctoral completion, with an added benefit being that most have been educated up to the bachelors degree level in their home nations, at no cost to the American taxpayer (Galama and Hosek 2008, Myers 1972). However, there is apparent <u>variation</u> in recent "intent to stay rates" among foreign S&E doctorates, where a greater proportion of newly minted S&E doctorates from lower income nations like China and India have expressed desires to stay and work in the United States compared to those from higher income nations (Finn 2005). Is variation in foreign S&E doctorate

[1] In this paper, rather than distinguishing between "developed" versus "developing" nations, the metric used for testing is national income in the form of per capita gross national income (GNI) by nation. Higher income nations are defined as having a relatively higher per capita GNI and lower income nations a lower per capita GNI.

"intent to stay rates" possibly related to differences in national income, also seen in foreign doctoral attainment between the five S&E fields? As Table 1 also shows, in 2005 the engineering field in particular was dominated by foreign doctorates while other S&E fields, most notably life sciences, had a smaller foreign doctoral presence. Therefore, a policy interest in both <u>where</u> the foreign doctorates came from and in <u>what</u> S&E fields they attained their doctorates is warranted. The focus of this paper is on how many foreign S&E doctoral students were educated at American universities from 1994 to 2005, in what S&E fields were they educated, and from where did they come.

With respect to the costs to the United States associated with this type of highly-skilled migration, alternate views see the increase in foreign S&E doctorates as potentially associated with negative externalities such as driving down wages and reducing incentives for US citizens to pursue advanced S&E degrees (Borjas 2005, Bracey 2008), universities exploiting foreign S&E graduate student labor (Rhee and Sagaria 2004), and loss of control over sensitive technologies related to national security (USCC 2005). Included in this general view are concerns that, "an over-reliance on the math and science talent of foreign students represents a major potential weakness in the future competitiveness and vitality of the U.S. economy and workforce" (ECS 2005). Recent literature also asks whether the increased presence of foreign S&E doctorates at American universities might be associated with wasteful S&E doctoral overproduction (Salzman and Lowell 2007, Goldman and Massy 2001, Butz et al 2003), suggesting a policy remedy where, "a general basis for selecting students to study in the United States (and for awarding visas) might be a commitment to study in a needed field; students whose specialties would alleviate national shortages would be favored" (Myers 1972 p. 334).

Related Policy Reports

A recent series of reports by business and academic groups have expressed concerns over the erosion of America's technological preeminence, and contain broad sets of recommendations for policy changes, primarily by universities and the federal government, designed to strengthen the nation's capacity to perform basic, university-based research, with a focus on cultivating talent in the sciences and engineering (AAU 2006). Examples of these reports include The Education Commission of the States, *Keeping America Competitive: Five Strategies To Improve Mathematics and Science Education*, July 2005; The Association of American Universities, *National Defense Education and Innovation Initiative, Meeting America's Economic and Security Challenges in the 21st Century*, January 2006; The National Academy of Sciences, Committee on Science, Engineering, and Public Policy, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*, February 2006; The National Summit on Competitiveness, *Statement of the National Summit on Competitiveness: Investing in U.S. Innovation*, December 2005; The Business Roundtable, *Tapping America's Potential: The Education for Innovation Initiative*, July 2005 (Kuenzi et al 2006). Additionally, the recent 50th anniversary of the Soviet Union's Sputnik launch in 1958 was met with popular reminiscences over the success of US government intervention, where the "fear of falling behind the Communists induced the federal government to pour a river of money in science and math education," with the result being the formation of a "vast cohort of scientists who gave us not only Apollo and the moon, but the sinews of the information age—for example, ARPA (created just months after Sputnik) created ARPANET, which became the internet—that have ensured American technological dominance to this day" (Krauthammer 2007, Time 2007). This paper aims to better characterize the foreign component of this "vast cohort of scientists" produced at American universities.

A recent example of US government interest in science and technology workforce issues related to foreign S&E doctorates is a RAND report sponsored by the Office of the Under Secretary of Defense for Personnel Readiness. The purpose of this report was to,

"consider information related to whether the United States is losing its edge in science and technology (S&T). Claims have been made about insufficient expenditures on research and development (R&D) (particularly on basic research), problems with US education in science and engineering (S&E), a shortage of S&E workers in the United States, increasing reliance on foreigners in the workforce, and decreasing attractiveness of S&E careers to US citizens. A loss of leadership in S&T could diminish US economic growth, standard of living, and national security" (Galama & Hosek 2008).

The report adds that research in the area of foreign students at American universities is deficient, and in attempting to better characterize their presence and impact,

"We have encountered additional areas for which substantial knowledge appears to be lacking and that may benefit from further research," to include "factors affecting the recruiting and retention of foreign S&E talent (i.e., a study on the decision of foreign students to do graduate and undergraduate work in the United States" (Galama & Hosek 2008).

This paper aims to in part fill this knowledge gap by better characterizing the foreign S&E doctoral population at American universities from 1994 to 2005.

Two Models

Research in this paper will test two models. The first model tests for variation in foreign doctoral attainment at American universities from 1994 to 2005 within each the five S&E fields of physical sciences, life sciences, engineering, mathematics and computer sciences, and social and behavioral sciences that can be explained by differences in the foreign students' home nation income, controlling for the varying sizes of national populations. The second model tests for associations between annual R&D funding growth and annual foreign S&E doctoral attainment growth in each of the five S&E fields based on differences in home nation income.

CHAPTER 2

Research Questions and Hypothesis for Model One

As discussed, two models will be presented in this paper testing for the influence of national income on foreign S&E doctoral attainment at American universities. Chapters 2 through 6 will present and test Model One. The research questions and hypothesis to be presented for Model One are related to a previous study asking, "How do we explain cross-national differences in the size of highly trained immigration to developed countries in general and to the United States in particular?" (Cheng and Yang, 1998 p. 628). The focus of Model One will be on testing for cross-national differences in S&E doctoral degree attainment based on national income. Is there variation in S&E doctoral degree attainment within any or all of the five S&E fields based on the different levels of national income of the foreign doctorates' home nations? It is initially theorized (null hypothesis) that foreign S&E doctorates from higher income nations act the same as those from lower income nations with respect to the types of S&E doctorates attained. For example, it is initially theorized that doctoral students at American universities from higher income nations like Germany or Japan are just as likely to attain a doctorate in each of the five S&E fields compared to doctoral students from lower income nations like China or India, controlling for the size of their respective national populations.

Therefore, the hypothesis for Model One is:

H-null: There is no variation in foreign doctoral attainment at American universities from 1994 to 2005 within each the five S&E fields of physical sciences, life sciences, engineering, mathematics and computer sciences, and social and behavioral sciences that can be explained by differences in the foreign students' home nation income, controlling for the varying sizes of national populations.

H-alternate: Variation in foreign S&E doctoral attainment within the five S&E degree fields can be explained by differences in home nation income, controlling for the varying sizes of national populations.

Model One will test the twelve-year aggregate number of foreign S&E doctorates attained by students representing 181 selected nations in each of the five S&E fields for the time period 1994 to 2005. The dependent variable is the total number of S&E doctorates attained from 1994 to 2005, by students from each of the 181 foreign nations. The independent variable selected is the level of national income in the form of per capita gross national income (GNI) for each of these 181 nations. The control variable is the national population for each of these 181 nations. Multivariate regression testing will be performed, one for each of the five S&E fields.

CHAPTER 3

Conceptual Framework for Model One

Highly-Skilled Migration

The presence of foreign S&E doctorates at American universities can be viewed as a case of highly-skilled migration, a current topic of public policy interest (Hamilton and Perry 2008, Hart 2006). The vehicle for this type of highly-skilled migration can be viewed in terms of foreign student pipelines from home nations to American universities. S&E doctoral education in general may be viewed in terms of screening, selection and training pipelines, beginning with mathematics and science education at the elementary school level, and ending with S&E graduate study (Salzman and Lowell 2007). With respect to foreign student pipelines, it is assumed that they consist of both formal and informal networks between American university S&E departments and foreign nations (Galama and Hosek 2008). It appears that some type of informal foreign S&E doctoral alumni network initially emerged that supported the recruitment and screening of potential applicants for admission to American university S&E doctoral programs, to include a "student grapevine" (Myers 1972, p. 336) providing information to prospective foreign S&E doctoral students. For example, a foreign-born American university S&E department faculty member with help from alumni and graduate students from that same nation might have served as the university's chief recruiter for promising students from his or her native country. The rise of these "migration networks" can also be viewed in terms of social capital, and as an intermediate form of organization between traditional markets and the formal educational hierarchy (Arango 2004). Recently foreign S&E student pipelines appear to have become more formalized. For example, George Mason University has established relationships with counterpart schools in China, aimed in part at attracting talented Chinese students to its Northern Virginia campuses (Mason Gazette 2005).

Foreign S&E students are also increasingly viewed by nations other than the United States as a talent pool to be targeted. For example Germany, concerned over technical workforce shortages, has attempted to attract these talented students to its home universities (GAES 2002). Similar intentions have been stated by the European Union (EU 2005), and Greece has announced plans to reform its university system for the purposes of both luring back overseas Greek S&E talent and convincing more of its own students to stay at home for university study. The stated belief here is that foreign S&E graduate students go to the United States to study due in part to the superiority of American universities and in part due to its dynamic S&E labor market. One way to help stem this domestic "brain drain" to the United States is to improve the quality of home nation universities (Economist 2006). Another of many examples is the reputation of Australia's universities for aggressively recruiting foreign students (Burn 2000). In short, an increasing number of nations have begun to compete with the United States to attract the talented foreign S&E student population. Current literature on the importance of global talent focuses on post-education workforce issues (Stephan and Levin 2001, Saxenian 2002, Finn 2005, Florida 2004). What distinguishes research in this paper is its focus on better measuring and characterizing a foreign S&E student population in terms of education-related pre-graduation student pipelines from home nations, rather than in the context of labor-related post-graduation migration. Finally, the measurement of migration to include highly-skilled migration to American universities is problematic, and the following caveat should be kept in mind,

"The first rule of migration studies is to visualize large error bars around virtually every statement one reads. Data are spotty at best, limiting researchers' confidence in comparisons over long periods of time, across many countries, and among ill-defined subpopulations such as the highly skilled (Hart 2006)."[2]

Therefore, this study is also aimed at reducing a "large error bar" associated with one type of highly-skilled migration measurement "across many countries," by providing a more detailed view of the national origins of the foreign S&E doctoral population at American universities from 1994 to 2005.

Hypothesizing the National Income Variable

The theorized workings of a national income variable are related to human capital theory and educational choices (Ehrenberg 1991, Catsiapis 1987, Wolf 1993, Becker 1993), where it is hypothesized that foreign students from lower income nations may have a

---

[2] This echoes a previous comment on the problems with accurate measurement of migration, where "International migration statistics are scarce and those that do exist must be interpreted with extreme caution" (Myers 1972 p.34).

greater inclination to remain in the S&E doctoral pipeline compared to counterparts from higher income nations due to the lower opportunity costs associated with doctoral degree attainment. A previous study offers a similar hypothesis that, "levels of professional migration are positively associated with disparities between sending countries and the United States in living conditions, research conditions, children's educational opportunities, political conditions, and professional employment opportunities" (Cheng and Yang, 1998 p. 628).[3]

However, an over representation in foreign S&E doctoral attainment by students from lower income nations may be viewed as contributing to a theorized overproduction of S&E doctorates, where US government intervention to increase S&E doctoral production (supply) is not efficiently calibrated to available jobs (demand) in the S&E labor market (Salzman and Lowell 2007, Butz et al 2003, Goldman and Massy 2001, Myers 1972). This theorized overproduction can be viewed in terms of *nonmarket failure,* due to governments lacking the "nonmarket mechanisms for reconciling calculations by decision makers of their private and organizational costs and benefits with the costs and benefits of society as a whole" (Wolf 1993). Proponents of this nonmarket failure view see inefficient overproduction of S&E doctorates at American universities as caused in part by US government education-related R&D funding. Given its zeal to promote a strong US S&E technical manpower base, the US government has fostered the creation of a greater supply of S&E doctorates than the labor market can accommodate (Salzman and

[3] It is assumed that the national income variable used in this paper's model testing is an accurate proxy for national differences in living conditions, research conditions, children's educational opportunities and professional employment opportunities.

Lowell 2007, Butz et al 2003, Goldman and Massy 2001). Evidence presented in support of this view includes the large numbers of S&E postdoctoral students unable to find employment (Bracey 2008, Salzman and Lowell 2007). How might this component of human capital theory be applied to foreign S&E doctoral attainment? An additional implication given here is that the foreign component of this surplus S&E doctoral population may tend to be from lower income nations, where these foreign students may view an American university doctorate more in terms as a path to US citizenship (Rhee and Sagaria 2004, Bracey 2008, Goldman and Massy 2001) and in terms of the shorter term economic benefits gained during the years of doctoral study (Goldman and Massy 2001, Myers 1972). However, creating a model to explain highly-skilled migration in solely economic (not in public policy terms) terms is problematic, due in part to the situation that, "political factors are nowadays much more influential than differential wages in determining mobility or immobility" (Arango 2004 p. 20). These political factors also may play a role in changed highly-skilled migration patterns, and the time period 1994 to 2005 selected for this study is justified from a previous study's results (Hamilton and Perry 2008) suggesting that foreign S&E doctoral attainment patterns at American universities changed in the post Cold War period.

Need for Disaggregated S&E Data

A limitation of a previous study of foreign doctoral attainment at American universities was its analysis of S&E data only in the aggregate (Hamilton & Perry 2008). Literature supports disaggregating highly-skilled migration data where, *"after surveying the literature, one of the main conclusions to be drawn is that disaggregated analysis of high-level migration is essential. Because there are pronounced variations, groupings by country, occupation, educational attainment, and the like should be included in analyses"* (Myers 1972 p. 35).

For example, doctoral attainment data disaggregated by S&E field can be used to test associations with R&D funding (Butz et al 2003) and for doctoral overproduction (Goldman & Massy 2001), and disaggregation of foreign S&E doctoral data is appropriate since,

"Although it is clear that foreign students face different incentives in graduate study, we must take departmental differences in research into account before we can observe different degree attainment for foreign students" (Goldman & Massey 2001, p. 74).

Data disaggregation can also check for the existence of *Simpson's Paradox*, where the behavior of one or more S&E fields might skew the aggregate results. What is true of the whole may not be true of the individual parts (Wonnacott & Wonnacott 1987). In this paper the "whole" is aggregate foreign S&E doctoral attainment for the five S&E fields, while the "individual parts" to be studied are foreign doctoral attainment for each field. Was there variation among the five S&E fields with respect to foreign S&E doctoral attainment at American universities?

CHAPTER 4

Methodology and Analysis for Model One

Model One: Methodology, Variables and Data

Methodology

The methodology used for Model One testing is an empirical approach based on observations, using foreign S&E doctoral attainment at American universities from 1994 to 2005 as the dependent variable, per capita gross national income (GNI) as the theorized independent (explanatory) variable, and national population as the control variable (Patten 2002, King et al 1994). Testing is by nation for 181 selected nations, in each of the following five S&E fields: physical sciences, life sciences, engineering, mathematics and computer sciences, and social and behavioral sciences. The approach followed here responds in part to a previous critique on the measurement of highly-skilled migration where it was observed that most prior studies used "small samples and such simple techniques as cross-tabulation or correlation. Albeit heuristic, these analyses fall short of providing solid evidence for understanding cross-country differences in highly-skilled migration on a world-wide scale" (Cheng and Yang 1998 p. 629). Similarly, "unlike most previous studies, which exclusively focused on professional migration from Third world countries to advanced ones" (Cheng and Yang 1998 p. 629), testing in this study analyzes highly-skilled migration to American universities from 181 nations in the world, from the highest income to the lowest income nations. This study will not test for individual reasons for highly-skilled migration (Cheng and Yang 1998). Rather, the focus here is on explaining it at the cross-national level. Further, other factors at work contributing to variation in foreign S&E doctoral attainment based on national origin are not tested for in this model. For example, variations in levels of foreign government financial aid for "sponsored" students studying at American universities (Myers 1972) and variations in restrictions on emigration by the sending nations due to political factors (Hamilton & Perry 2008, Myers 1972) are not tested for. Finally, the terrorist attacks of September 11, 2001 might have affected foreign S&E doctoral student migration during this time period due to selective US government immigration restrictions (House Science Committee 2004), foreign government restrictions, or decisions by foreign students to return to their home nations before degree completion. Given the assumption that all foreign students, even those completing their S&E doctorates in 2005, were in the United States in September 2001 and enrolled in American universities with student visas, the effects of the events of September 11 on model testing might be relatively small. A larger effect on foreign S&E doctoral attainment might be seen in the years after 2005 (corresponding to student visa requests submitted after September 2001).

The model is presented where,

$$Y = \beta 0 + \beta 1X1 + \beta 2X2$$

Where,

Y = dependent variable: total number of foreign S&E doctorates, aggregated for the time period 1994 to 2005, by nation, 181 nations, for each of the following five S&E fields comprising foreign S&E doctorates attained at American universities: physical sciences, life sciences, engineering, mathematics and computer sciences, and social and behavioral sciences

X1 = Independent variable: median annual per capita gross national income (GNI) for the years 1994 to 2005, by nation, for 181 nations

X2 = Control variable: total population, by nation, 181 nations, for the year 1992

$\beta 0$ = intercept term

$\beta 1$ = estimated regression coefficient associated with X1

$\beta 2$ = estimated regression coefficient associated with X2

The regression model will test each of the five S&E fields. If the independent variable per capita GNI is statistically significant at $p<0.05$, then this result would cause failure to accept the null hypothesis for that particular S&E field.

Variables

Dependent Variable

Data for the selected dependent variable to be tested are from the Survey of Earned *Doctorates* (SED) (NSF/NIH/USED/NEH/USDA/NASA 2009). The dependent variable is the aggregate number of S&E doctorates attained by foreign students at American universities during the time period 1994 to 2005, by nation for 181 selected nations, in each of the following five S&E fields: physical sciences, life sciences, engineering, mathematics and computer sciences, and social and behavioral sciences. The nations are listed in Appendix B with corresponding aggregate doctoral counts for the combined five S&E fields. The aggregate counts for all nations with 25 or greater S&E doctorates attained are listed, and the counts for those nations with less than 25 S&E doctorates attained during the time period 1994 to 2005 are listed as "<25". Again, these are not annual but rather aggregate counts for the twelve year time period 1994 to 2005. The SED is not a sample survey. Rather, all foreign S&E doctorates at American universities from 1994 to 2005 were surveyed.[4]

Measurement of the dependent variable is in terms of annual doctoral counts per nation, per year and per S&E field. These annual counts are in the form of a series of simple data strings, and they serve as the foundation for all data analysis in this paper. Table 2 is an example of a simple data string for a given "Nation A" in life sciences over a twelve year time period corresponding to the years 1994 to 2005.

Table 2 Example of a Twelve Year Time Period Data String

Year	1	2	3	4	5	6	7	8	9	10	11	12	Total
	8	9	6	12	11	15	17	22	18	20	26	29	193

Again, the data string in this example represents the annual count of foreign doctorates attained at American universities during a twelve year period for life sciences for the designated "Nation A." The doctoral count for "Nation A" in Year One is 8, 9 for Year

[4] The SED response rate for "country of citizenship" in 2007 was 92.3 percent. "Because the graduate schools collect the questionnaires from degree recipients at the time of doctoral completion, the universe for doctorate recipients is also quite complete…Student nonresponse was concentrated in certain institutions. Graduates from 21 of the over 420 institutions in the SED accounted for over 50 percent of nonrespondents." Measurement error due to error in recording data is calculated at less than one percent (NSF/NIH/USED/NEH/USDA/NASA 2009).

Two, 6 for Year Three, and so on until the final count of 29 for Year Twelve. The sum total of doctoral counts for "Nation A" for life sciences for the twelve year period is 193. This data string for life sciences is an example of the dependent variable (e.g., aggregate life sciences doctoral count of 193 for "Nation A") to be tested for each of the 181 nations for each of the five S&E fields.

Independent Variable: National Income

A national income variable will be used to test for whether a foreign doctorates' home nation income explains the aggregate numbers of S&E doctorates attained at American universities from the selected 181 nations during the time period 1994 to 2005. Specifically, any statistical significance (at $p<0.05$) of the national income variable would suggest that S&E doctoral attainment patterns differ between those students from higher income nations and those from lower income nations. The data for this variable are per capita gross national income (GNI) by nation, taken from the United Nations Statistics Division Statistical Database (UN 2009). The per capita GNI values in US dollars corresponding to each of the selected 181 nations are listed in Appendix B. This variable is the median annual per capita GNI per nation, for 181 nations, for the years 1992 to 2000.[5] Test results showing significance at $p<0.05$ with a negative regression coefficient means that foreign S&E doctorates tended to migrate from lower income nations. A significant positive regression coefficient means that foreign S&E doctorates tended to

---

[5] For this time period, the correlated association between mean and median per capita GNI for the 181 nations is 0.99. Therefore, using mean values should return highly similar regression test results.

come from higher income nations. More information about the income variable for the 181 nations will be presented in the "data analysis" section.

Model One will test for the affect of a $100 increase in per capita national income on foreign S&E doctoral attainment. For the 181 nations, the mean per capita income is $6,265, with a standard deviation of $9,122, indicating that the national income distribution curve is skewed by higher income nations. The minimum per capita GNI for the 181 nations is $102, and the maximum is $42,375. The regression coefficient quantifies the change in the number of doctorates attained associated with a $100 increase in national income. If the regression test result for the national income variable for a given S&E field is significant at $p<0.05$, then the regression coefficient indicates the change in the number of the number of S&E doctorates attained by foreign students in that field explained by an increase of $100 in the students' home nation per capita GNI. If the regression test result for the national income variable for a given S&E field is not significant at $p<0.05$, then the regression coefficient is determined to be zero, meaning no change in foreign S&E doctoral attainment is explained by a $100 increase in the foreign students' home nation per capita GNI. Finally, since the standard deviation is $9,122, a $100 change in national income represents 0.01 standard deviation units.

Control Variable: National Population

A national population variable serves as a control, since nations with large populations may tend to have more students at American universities and dominate the doctoral counts. A previous study on highly-skilled migration also "used the population size of the sending country as a proxy for the potential pool of professional immigrants," where population size used as a statistical control, "should be positively associated with the level of professional migration" (Cheng and Yang 1998 p. 640). The control variable used in this study is total population by nation, for 181 nations, for the year 1992, taken from the U.S. Census Bureau IDB (US Census Bureau 2009). The total national populations corresponding to each of the selected 181 nations are listed in Appendix B. The population variable is very robust, meaning that relative population changes between nations vary little from year to year during relatively long time periods. For example, correlation testing between changes in the 181 national populations from 1992 to 2000 shows a 0.99 association.[6]

Initial Characterization of the Foreign S&E Doctoral Population Data

Table 3 provides an initial characterization of the foreign S&E doctoral population at American universities, by aggregate count and percentages of the total, 1994 to 2005, by S&E field, for the selected 181 nations. During the time period 1994 to 2005, there was a total of 96,466 doctorates attained at American universities in the five S&E fields by foreign students (non-immigrant, temporary resident/student visa) from the selected 181 nations. The field with the largest representation was engineering, with 32,830 doctorates attained, comprising 34 percent of the total. The field with the smallest representation was mathematics and computer sciences, with 10 percent of the total. As

[6] In a check for multicollinearity for the time period 1994 to 2005, the correlated association between the two independent variables, national population and per capita GNI, is -0.07. The variance inflation factor (VIF) is 1.0 and 1/VIF is 0.995, suggesting no problem with multicollinearity.

will be shown, foreign S&E doctoral attainment is dominated by students from four nations, China, India, Taiwan and South Korea.

Table 3 Foreign S&E Doctoral Population, 1994 to 2005

	Physical Sciences	Life Sciences	Engineering	Mathematics and Computer Sciences	Social and Behavioral Sciences	Total
Doctorates	16,161	23,946	32,830	10,031	13,498	96,466
Percentage of Total	17	25	34	10	14	100

Source: NSF/NIH/USED/HEH/USDA/NASA (2009)

Model One Testing Results

The regression test results for 181 nations are shown in Table 4, to include the mean number of S&E doctorates attained per nation for the time period 1994 to 2005, and its standard deviation. For example, in the physical sciences the mean number of doctorates attained by foreign students from the 181 nations was 6.1 per one million of each nation's population, with a standard deviation of 14.3. Test results indicate that for the time period 1994 to 2005, for the foreign S&E doctoral population, three of the S&E fields tended to be represented by students from higher income nations, after controlling for national populations. For the three S&E fields of physical sciences, mathematics and computer sciences, and social and behavioral sciences, the p-value is less than .05. Therefore, for these three S&E fields the regression coefficients are significant and the null hypothesis is not accepted.

Table 4 Regression Results for National Income Variable, 181 Nations

SE Field	Mean	Standard Deviation	Regression Coefficient	p-value	Adjusted R-squared
Physical Sciences	6.1	14.3	0.34	0.04	0.76
Life Sciences	9.9	21.2	0.41	0.07	0.76
Engineering	8.9	21.4	0.47	0.18	0.74
Mathematics and Computer Sciences	4.3	10.2	0.2	0.02	0.77
Social and Behavioral Sciences	7.5	18.2	0.49	0.001	0.32

As a result, there is failure to reject the alternate hypothesis that there is variation in foreign doctoral attainment at American universities from 1994 to 2005 within each the three S&E fields of physical sciences, mathematics and computer sciences, and social and behavioral sciences that can be explained by differences in the foreign students' home nation income (controlling for the varying sizes of national populations). Since the regression coefficients are positive, these results also indicate that foreign doctorates in these three S&E fields tended to come from higher income nations during the time period 1994 to 2005. However, there is failure to reject the null hypothesis for the life sciences ($p=0.07$) and engineering ($p=0.18$). The following are discussions of the three fields with statistically significant test results of $p<0.05$.

Physical Sciences

Statistically significant at $p=0.04$. The Adjusted R-squared score is 0.76. The mean value for doctorates attained in physical sciences is 6.1, meaning there were 6.1 doctorates per one million of that nation's population at American universities in physical sciences. The regression coefficient for the national income variable is 0.34, a positive value. This means that for every $100 increase in per capita national income, that nation was represented by 0.34 more physical sciences doctorates at American universities. These results indicate that foreign doctorates in this field tended to come from higher income nations during the time period 1994 to 2005.

Mathematics and Computer Sciences:

Statistically significant at p=0.02. The Adjusted R-squared score is 0.77. The mean value for doctorates attained in mathematics and computer sciences is 4.3, meaning there were 4.3 doctorates per one million of that nation's population at American universities in mathematics and computer sciences. The regression coefficient for the national income variable is 0.2, a positive value. This means that for every $100 increase in per capita national income, that nation was represented by 0.2 more mathematics and computer sciences doctorates at American universities. These results indicate that foreign doctorates in this field tended to come from higher income nations during the time period 1994 to 2005.

Social and Behavioral Sciences:

Statistically significant at p=0.001. The Adjusted R-squared score is 0.32. The mean value for doctorates attained in social and behavioral sciences is 7.5, meaning there were 7.5 doctorates per one million of that nation's population at American universities in social and behavioral sciences. The regression coefficient for the national income variable is 0.49, a positive value. This means that for every $100 increase in per capita national income, that nation was represented by 0.49 more social and behavioral sciences doctorates at American universities. These results indicate that foreign doctorates in this field tended to come from higher income nations during the time period 1994 to 2005.

Data Analysis

Next, foreign S&E doctoral attainment data for the 181 nations at American universities from 1994 to 2005 is disaggregated into four national income quartiles and presented in Appendix C by S&E field in order to give a better view of what specific nations are represented in doctoral attainment with respect to differing levels of national income. The following are the per capita GNI ranges of the nations for the four national income quartiles used in this data analysis:

Quartile One: 46 nations with per capita GNI greater than $7,500

Quartile Two: 45 nations with per capita GNI less than $7,500 and greater than $1,750

Quartile Three: 45 nations with per capita GNI less than $1,750 and greater than $550

Quartile Four: 45 nations with per capita GNI less than $550

The data presented in Appendix C includes all nations with aggregate S&E doctoral counts of 25 or greater for the time period 1994 to 2005. What is most striking about foreign S&E doctoral attainment at American universities from 1994 to 2005 as shown in Appendix C is the large representation by students from China, India, South Korea and Taiwan. Also striking is the large share of doctorates in certain S&E fields among the lower income nations (national income Quartiles Three and Four) that were attained by students from China and India. For example, in engineering among the 45 nations comprising the lowest national income Quartile Four (those nations with a per capita GNI of less than $550), Indian students attained 90 percent of all doctorates during the 1994 to 2005 time period, with students from only six other nations, Bangladesh, Ghana, Nigeria, Nepal, Ethiopia and Kenya attaining 25 or more doctorates (refer to Appendix C). Similarly among the 45 nations comprising national income Quartile Three (those nations with a per capita GNI of greater than $550 and less than $1,750), Chinese students attained over three-quarters of all doctorates in physical sciences, life sciences and engineering (Appendix C).

These results show that with the exception of India, students from lowest income nations in Quartile Four tend not to attain the same types and numbers of doctorates as their higher income nation counterparts. An extreme example is mathematics and computer sciences, where Indian students attained 1,201 out of the total 1,340 doctorates, or 89.6 percent of all Quartile Four doctorates during the 1994 to 2005 time period. Students from only one other nation, Bangladesh, attained 25 or more doctorates, and this total count was only 29 (Appendix C). Note that this doctoral count of 29 is the aggregate doctoral count for the twelve-year time period 1994 to 2005. In other words, the students from the Quartile Four nation with the second largest doctoral count, Bangladesh, attained only a little more than 2 mathematics and computer sciences doctorates per year at American universities. The other 43 lowest income nations comprising Quartile Four attained a lower number than Bangladesh, and many received none. In short, among the Quartile Four nations, when excluding India, students from these of the lowest income nations were greatly under represented at American universities during the time period 1994 to 2005.

Data in Appendix C also show a relatively greater presence by Quartile Two and Three students from nations like Russia, Turkey, Mexico, Thailand, Brazil, Poland, Argentina, Colombia, Malaysia, Romania, Sri Lanka, Pakistan and Egypt. Of special note here is the growth in doctoral attainment by students from Russia and selected Eastern European nations in certain S&E fields in the post Cold War era. For example, from 1977 to 1988 students from the entire Soviet Union attained no S&E doctorates at American universities. From 1994 to 2005 the number for Russia alone had increased to 1,663. Similarly, the number of Romanian students increased from near zero to 1,070 during these two time periods (NSF/NIH/USED/HEH/USDA/NASA 2009). These findings support previous results suggesting that foreign S&E doctoral attainment migration patterns changed in the post Cold War era (Hamilton and Perry 2008), and further justify 1994 to 2005 as an appropriate time period to conduct this analysis.

Compared to the group of Quartile Four nations, representation by nations within the group of Quartile Two and Three nations was more diverse and numerous, although their total doctoral counts were still relatively small compared to students from Taiwan and South Korea. In the case of South Korea and Taiwan (national income Quartile One), these two nations comprised over 40 percent of the doctorates attained among the 46 nations of Quartile One in all five S&E fields. A check for variation between the four national income quartiles showed greater numbers of nations with 25 or more S&E doctorates attained among the higher income nations represented. For example, Appendix C shows that in engineering, Quartile One had 36 nations with 25 or more doctorates attained, while Quartile Two had 19 nations with 25 or more engineering doctorates attained, and Quartiles Three and Four had 15 and 7 nations respectively. The same structure is seen in other S&E fields, where the groups of higher income nations have a more diverse representation compared to lower income nations. This finding that there are more nations with 25 or more doctorates among the higher national income quartiles also supports the regression test results that indicated that in three S&E fields when controlling for population, students from higher income nations tended to attain more doctorates. In other words, the regression results indicate that even though China and India had large S&E doctoral student contingents at American universities from 1994 to 2005, highly-skilled migration patterns were still somewhat skewed in favor of students from higher income nations in three of the five S&E fields (physical sciences, mathematics and computer sciences, and social and behavioral sciences).

However, the data in Appendix C clearly show that foreign S&E doctoral attainment at American universities was dominated by students from China, India, South Korea and Taiwan. During the time period 1994 to 2005, students from these four nations attained 52,953 S&E doctorates, or 55 percent of the foreign total, as shown in Table 5.

Table 5 S&E Doctorates from China, India, South Korea and Taiwan, 1994 to 2005

Nation	Total SE doctorates 1994 to 2005	Percentage of total
China	23,375	24
India	10,836	11
South Korea	10,500	11
Taiwan	8,242	9
Total	52,953	55
Total for 181 nations	96,466	100

Source: NSF/NIH/USED/HEH/USDA/NASA (2009)

China was the clear stand out with 23,375 S&E doctorates, or a 24 percent share of the total, while South Korea (total of 10,500 S&E doctorates) and Taiwan (total of 8,242 S&E doctorates), with relatively small populations, showed similar doctoral counts to India (10,836 S&E doctorates), with a much larger population. When controlling for population, it appears that Taiwan and South Korea are outliers, with relative S&E doctoral representation far exceeding their national populations compared to the other 179 nations studied.

A discussion of South Korea and Taiwan as potential outliers is presented in Appendix D. In contrast to South Korea and Taiwan, China and India appear to be rather normal in their S&E doctoral representation on American campuses from 1994 to 2005 after controlling for their large national populations. As Appendix D shows, after controlling for variation in national population size, China's doctoral representation is similar to higher income nations like Germany and the United Kingdom in certain S&E fields.

Further, even though Table 5 shows India as having 10,836 S&E doctorates, or 11 percent of the foreign S&E total from 1994 to 2005, after controlling for its large population, it was actually under represented on American campuses compared to the mean doctorate-to-population values for the 179 nations (after excluding Taiwan and South Korea). Therefore, a second regression model is tested for 179 nations after excluding South Korea and Taiwan as outliers, while China and India are retained. The results are shown in Table 6.

Table 6 Regression Results for National Income Variable, 179 Nations

S&E Field	Mean	Standard Deviation	Regression Coefficient	p-value	Adjusted R-squared
Physical Sciences	5.8	13.9	0.24	0.07	0.83
Life Sciences	9.2	20	0.24	0.13	0.87
Engineering	7.6	16.7	0.15	0.34	0.93
Mathematics and Computer Sciences	4	9.9	0.13	0.01	0.9
Social and Behavioral Sciences	7.1	17.9	0.37	0	0.63

Regression results for 179 nations

For the two S&E fields of the mathematics and computer sciences, and social and behavioral sciences, the p-value is less than .05, and the regression coefficients are positive. Therefore the relationships are statistically significant at $p < 0.05$, and the null hypothesis is not accepted. As a result, there is failure to reject the alternate hypothesis that there is variation in foreign doctoral attainment at American universities from 1994 to 2005 within the two S&E fields of mathematics and computer sciences, and social and behavioral sciences that can be explained by differences in the foreign students' home nation income, controlling for the varying sizes of national populations. These results indicate that foreign doctorates in these two S&E fields tended to come from higher income nations during the time period 1994 to 2005. However, there is failure to reject the null hypothesis for the physical sciences (p=0.07), life sciences (p=0.13) and engineering (p=0.38). The following are discussions of the two fields with statistically significant test results.

Mathematics and Computer Sciences

Statistically significant at p=0.01. The Adjusted R-squared score is 0.9. The regression coefficient for the national income variable is 0.13, a positive value. This means that for every $100 increase in national income, that nation was represented by 0.13 more mathematics and computer sciences doctorates at American universities. These results indicate that foreign doctorates in this field tended to come from higher income nations during the time period 1994 to 2005.

Social and Behavioral Sciences

Statistically significant at p=0.000. The Adjusted R-squared score is 0.63. The regression coefficient for the national income variable is 0.37, a positive value. This means that for every $100 increase in national income, that nation was represented by 0.37 more social and behavioral sciences doctorates at American universities. These results indicate that foreign doctorates in this field tended to come from higher income nations during the time period 1994 to 2005. The p-value (p=0.000) is the most highly significant of the five S&E fields, and suggests that social and behavioral sciences doctorates tended to be dominated by students from higher income nations, even more so than even the physical sciences and mathematics and computer sciences. This finding supports the theory that higher income nations possess greater "social capabilities" and "absorptive capacity" as reflected in their more complex social, political and economic institutions (Abramovitz 1986), and thus there may have been a greater home nation labor market demand for social and behavioral sciences doctorates attained at American universities by students from higher income nations.

Effect of Excluding Taiwan and South Korea

The effect of excluding Taiwan and South Korea from testing can been seen by comparing the regression results in Tables 4 and 6. When including the two nations, the national income variable for the physical sciences is statistically significant at $p<0.05$ ($p=0.04$). In contrast, test results excluding Taiwan and South Korea ($p=0.07$) are not significant at $p<0.05$. Excluding Taiwan and South Korea also resulted in increased Adjusted R-squared values. Further, social and behavioral sciences differ from the other four S&E fields in two respects. First, its Adjusted R-squared value (0.32) is relatively low especially when testing for 181 nations. However, when testing for 179 nations (excluding Taiwan and South Korea), the Adjusted R-squared value increases to 0.63. The p-value ($p=0.000$) is the most highly significant of the five S&E fields, and suggests that social and behavioral sciences doctorates tended to be dominated by students from higher income nations, even more so than even the physical sciences and mathematics and computer sciences.

CHAPTER 5

Changes in Foreign Doctoral Attainment: 1994 to 2005

Appendix E shows annual changes in foreign S&E doctoral attainment from 1994 to 2005. For each of the five S&E fields in Appendix E, annual doctoral counts are presented for the nations comprising each of the four national income quartiles (Q1, Q2, Q3, and Q4) and also annual doctoral counts for China, India, South Korea and Taiwan. Again note that Quartile One (abbreviated as Q1 in the appendix) is the group of nations with the highest per capita GNI, and Quartile Four (abbreviated as Q4 in the appendix) is the group of nations with the lowest per capita GNI. Quartile 2 and Quartile 3 nations (abbreviated as Q2 and Q3) are those groups of nations with the second and third highest national incomes by national income quartile. Further, for this analysis South Korea and Taiwan are not included in the Quartile One S&E doctoral counts, while China and India are not included in the Quartile Three (China) and Quartile Four (India) counts.

When viewing the data in Appendix E across the five S&E fields, what is most striking are the very large growth rates in Chinese doctorates from 1994 to 2005, in contrast to modest growth trends from India, modest or no growth from South Korea, and relatively large decreases in doctoral attainment by Taiwanese students. South Korea and especially Taiwan appeared to become less and less outliers as the time period progressed, while by 2005 China appeared to emerge as the new outlier. Also striking were the very low doctoral counts for the Quartile Four nations, excluding India. There was also variation in foreign S&E doctoral growth rates during the time period 1994 to 2005. Overall growth rates were higher in the later years (e.g. 2002 to 2005), and lower in the earlier ones for all five S&E fields. Based upon the tables in Appendix E, the following data details and discussion are presented for each of the five S&E fields.

Physical Sciences

The number of physical sciences doctorates attained by Chinese students increased from 113 in 1994 to 646 in 2005, representing a factor increase of 5.7. For all other foreign students from the 180 nations excluding China, the total number of physical sciences doctorates increased from 930 in 1994 to 1161 in 2005, a factor increase of only 1.2. In other words, growth in Chinese physical sciences doctorates was almost five times greater than growth for the other 180 nations combined. The Chinese share of total physical sciences doctorates attained by foreign students increased from 11 percent in 1994 to 36 percent in 2005. Doctoral counts by South Korean and Taiwanese students decreased during this time period, while India saw mostly lower doctoral counts after 1994 until there was an increase from 2004 to 2005. A comparison between China and India is instructive. In 1994, physical sciences doctoral attainment for these two nations was roughly equal, with 128 attained by Indian students and 113 attained by Chinese students. However, by 2005 China had more than four times as many physical sciences doctorates than India, 646 for Chinese students and 143 for Indian students. A comparison between China and the lower income nations of Quartiles Two, Three and Four excluding India is also instructive. In 2005, total Chinese physical sciences doctorates (total of 646 doctorates) outnumbered the total for the 134 nations comprising Quartile Two, Three and Four nations excluding India (total of 524 doctorates). Also note the very small representation from the 43 lowest income nations (Quartile Four) excluding India (total of only 62 doctorates in 2005).

Life Sciences

The number of life sciences doctorates attained by Chinese students increased from 124 in 1994 to 781 in 2005, representing a factor increase of 6.3. For all other foreign students from the 180 nations excluding China, the total number of life sciences doctorates increased from 1,482 in 1994 to 1,690 in 2005, a factor increase of only 1.2. In other words, growth in Chinese life sciences doctorates was more than five times greater than growth for the other 180 nations combined. The Chinese share of total life sciences doctorates attained by foreign students increased from 8 percent in 1994 to 32 percent in 2005. Doctoral counts by Taiwanese students decreased during this time period, South Korean counts remained fairly steady, while Indian doctoral counts doubled from 182 in 1994 to 352 in 2005. The gap between Chinese and Indian life sciences doctoral attainment is smaller than in the physical sciences, but still sizeable. In 1994, there were 182 life sciences doctorates attained by Indian students and 124 attained by Chinese students. However, by 2005 China had more than twice as many life sciences doctorates than India, 781 for Chinese students and 352 for Indian students. A comparison between China and the lower income nations of Quartiles Two, Three and Four excluding India is again instructive. In 2005, total Chinese physical sciences doctorates (total of 781 doctorates) outnumbered the total for the 134 nations comprising

Quartile Two, Three and Four nations excluding India (total of 664 doctorates). Again note the very small representation from the 43 lowest income nations (Quartile Four) excluding India (total of only 84 doctorates in 2005).

Engineering

The number of engineering doctorates attained by Chinese students increased from 136 in 1994 to 1,519 in 2005, representing a factor increase of 11.2. For all other foreign students from the 180 nations excluding China, the total number of engineering doctorates increased from 2,299 in 1994 to 2413 in 2005, a factor increase of only 1.05. In other words, growth in Chinese engineering doctorates was greater than ten times that for the other 180 nations combined. The Chinese share of total engineering doctorates attained by foreign students increased from 6 percent in 1994 to 39 percent in 2005. Doctoral counts by Taiwanese students decreased sharply during this time period from 562 in 1994 to only 170 in 2005, while Indian and South Korean doctoral counts showed a modest increase. A comparison between China and India is again instructive. In 1994 Indian students attained 464 engineering doctorates, more than triple the 136 attained by Chinese students. However, by 2005 this relationship had reversed as China had almost three times as many engineering doctorates than India, 1,519 for Chinese students and 564 for Indian students. A comparison between China and all 177 nations excluding India, South Korea and Taiwan underscores the dominance of Chinese student doctoral attainment in engineering. In 2005, total Chinese engineering doctorates (total of 1,519 doctorates) outnumbered the total for the 178 nations comprising Quartile One, Two, Three and Four nations excluding India, South Korea and Taiwan (total of 1,200 doctorates). Again note the very small representation from the 43 lowest income nations (Quartile Four) excluding India (total of only 73 doctorates in 2005).

Mathematics and Computer Sciences

The number of mathematics and computer sciences doctorates attained by Chinese students increased from 36 in 1994 to 527 in 2005, representing a factor increase of 14.6. For all other foreign students from the 180 nations excluding China, the total number of mathematics and computer sciences doctorates increased from 669 in 1994 to 815 in 2005, a factor increase of only 1.2. In other words, growth in Chinese mathematics and computer sciences doctorates was more than twelve times greater than growth for the other 180 nations combined. The Chinese share of total mathematics and computer sciences doctorates attained by foreign students increased from 5 percent in 1994 to 39 percent in 2005. Doctoral counts by South Korean students increased somewhat, those for Taiwanese students decreased by half, and those for Indian students mostly decreased during this time period. As with the previous S&E fields, Chinese doctoral growth contrasts to Indian slow or no growth. A comparison between China and the other 177 nations excluding India, South Korea and Taiwan shows roughly equal doctoral attainment in 2005. In 2005, total Chinese mathematics and computer sciences doctorates (total of 527 doctorates) was one less than the 177 nation total of 528 doctorates. Note the extremely small representation from the 43 lowest income nations (Quartile Four) excluding India (total of only 19 doctorates in 2005).

Social and Behavioral Sciences

Note that social and behavioral sciences is the only S&E field of the five with a semblance of balanced growth between the higher and lower income nations. Even though its total counts increased from 26 in 1994 to 181 in 2005, China's share of total foreign doctorates increased only modestly during this period from 8 percent to 13 percent. The share taken by the highest income nations comprising Quartile One was mostly unchanged, from 32 percent in 1994 to 29 percent in 2005. This relatively large share of total doctorates attained by students from the higher income nations contrasts with the other four S&E fields, and again supports the theory that higher income nations possess greater "social capabilities" and "absorptive capacity" as reflected in their more complex social, political and economic institutions (Abramovitz 1986). Finally, the lowest income nations comprising Quartile Four showed at least some representation by the year 2005, with a 4 percent share of all foreign social and behavioral sciences attained. This result suggests that the social and behavioral sciences had a more balanced foreign student representation with respect to variation in the national incomes of their home nations compared to the other four S&E fields.

CHAPTER 6

Model One Revised

As shown in the previous section and in Appendix E, there was variation in foreign S&E doctoral growth rates from 1994 to 2005, indicating a change in highly-skilled migration patterns during this time period. The growth rates were higher in the later years (e.g. 2002 to 2005), and lower in the earlier ones for all five S&E fields. These higher growth rates appear to be associated in large part with the growth in doctorates by students from China. The two regression models previously used, one for 181 nations and the other for 179 nations (excluding South Korea and Taiwan), do not capture these changes in migration patterns, since the S&E doctoral attainment data were tested in the aggregate. In this section the regression model is therefore modified to test for the explanatory power of the national income and population variables in two selected years, 1997 and 2005, using the same methodology, data and variables as previously presented. The goal here is to see whether regression testing results for the two explanatory variables for the separate years 1997 and 2005 are different, possibly due to changes in highly-skilled migration patterns over this time period. The initial regression test is for each of the five S&E fields, by year, for the two separate years 1997 and 2005, for 181 nations (South Korea and Taiwan included). Next, China is excluded and testing is performed on the remaining 180 nations. Do testing results for the 181 nations compared to results for 180 nations (excluding China) for the individual years 1997 and 2005 indicate that growth in Chinese doctoral attainment seen after 1997 skewed the model? In other words, to restate a version of the original research question, after excluding China in 1997 and in 2005, did foreign S&E doctorates tend to come from higher or lower income nations?

Testing for 181 Nations

The results for the initial test for 181 nations using the same methodology as previous model testing are presented in Table 7. Again, note that China, South Korea and Taiwan are included in this testing. Table 7 shows regression results for the national income and population variables by S&E field, for 181 nations, for the separate years 1997 and 2005. Results show the change in the statistical significance of the national income variable from 1997 to 2005.

1997

In 1997 the national income variable was significant at $p<0.05$ and the income regression coefficient (IRC) positive in three fields, indicating that these S&E doctoral fields tended to be represented by students from higher income nations, after controlling for population. The three S&E fields showing significant p-values for the national income variable were physical sciences, mathematics and computer sciences, and social and behavioral sciences. In 1997 the national income variable was statistically significant at $p=0.02$ for physical sciences, $p=0.025$ for mathematics and computer sciences, and $p=0.003$ for social and behavioral sciences.

Table 7 Revised Model One Testing Results: 1997 and 2005, 181 Nations

181 Nations

Physical Sciences

Year	p_value income	IRC	p_value population	PRC	Adj. R2
1997	**0.02**	**0.27**	**0**	**0.24**	**0.78**
2005	**0.16**	**0.29**	**0**	**0.4**	**0.76**

Life Sciences

Year	p_value income	IRC	p_value population	PRC	Adj. R2
1997	**0.068**	**0.36**	**0**	**0.33**	**0.71**
2005	**0.093**	**0.35**	**0**	**0.55**	**0.85**

Engineering

Year	p_value income	IRC	p_value population	PRC	Adj. R2
1997	**0.19**	**0.37**	**0**	**0.45**	**0.67**
2005	**0.36**	**0.42**	**0**	**1**	**0.8**

Mathematics and Computer Sciences

Year	p_value income	IRC	p_value population	PRC	Adj. R2
1997	**0.025**	**0.15**	**0**	**0.11**	**0.69**
2005	**0.35**	**0.15**	**0**	**0.33**	**0.77**

Social and Behavioral Sciences

Year	p_value income	IRC	p_value population	PRC	Adj. R2
1997	**0.003**	**0.38**	**0**	**0.08**	**0.26**
2005	**0.002**	**0.45**	**0**	**0.14**	**0.42**

IRC is Income Regression Coefficient
PRC is Population Regression Coefficient

Also note the very high significance of the population variable ($p<0.001$) for all five S&E fields, and relatively high Adjusted R-squared values for all S&E fields except social and behavioral sciences. For these four fields, a large component of the variation in foreign doctoral attainment is explained by the population variable These results are similar to a previous finding that, "Population size of the sending country-the control variable-does have the largest effect on professional migration…As anticipated, large countries do send more professional immigrants than smaller ones, other things being equal" (Cheng and Yang 1998, p. 648).

2005

By 2005 the significance of the national income variable was no longer seen in physical sciences and mathematics and computer sciences. Mathematics and computer sciences showed the greatest change. The regression results for the national income variable for 2005 were not significant with a p-value of 0.35, a large change from the p-value of 0.025 in 1997. These results contrast with life sciences. The p-values for the national income variable from 1997 to 2005 were little changed and near significance at $p<0.05$. Finally, social and behavioral sciences is distinguished from the other four S&E fields with its strongly significant p-value for national income and low Adjusted R-squared value for both 1997 and 2005. These results again suggest that there was variation between the models explaining the five S&E fields in the same year and over time. Also note that the national income variable regression coefficients for all S&E fields were positive and almost unchanged from 1997 to 2005.

Testing for 180 Nations, Excluding China

Next, Table 8 shows regression results for the national income and population variables by S&E field, for 180 nations excluding China, for the separate years 1997 and 2005. The results indicate that excluding China from the model results in greater significance of the national income variable in certain S&E fields, compared to testing for 181 nations.

1997

In 1997 the national income variable was significant at $p<0.05$ and the income regression coefficient (IRC) positive in three fields, indicating that these S&E doctoral fields tended to be represented by students from higher income nations, after controlling for population. The three S&E fields showing significant p-values for the national income variable were physical sciences, mathematics and computer sciences, and social and behavioral sciences. In 1997 the national income variable was statistically significant at $p=0.01$ for physical sciences, $p=0.023$ for mathematics and computer sciences, and $p=0.002$ for social and behavioral sciences. These results were similar to testing for 181 nations. While there was again a very high significance of the population variable ($p<0.001$) for all five S&E fields, there were relatively lower Adjusted R-squared values for all S&E fields, indicating that explanatory value is lost when China is excluded from the testing.

Table 8 Revised Model One Testing Results: 1997 and 2005, 180 Nations

180 Nations, excluding China

Physical Sciences

Year	p_value income	IRC	p_value population	PRC	Adj. R2
1997	**0.01**	**0.26**	**0**	**0.16**	**0.48**
2005	**0.024**	**0.26**	**0**	**0.18**	**0.44**

Life Sciences

Year	p_value income	IRC	p_value population	PRC	Adj. R2
1997	**0.06**	**0.35**	**0**	**0.24**	**0.37**
2005	**0.039**	**0.34**	**0**	**0.37**	**0.64**

Engineering

Year	p_value income	IRC	p_value population	PRC	Adj. R2
1997	**0.18**	**0.38**	**0**	**0.52**	**0.53**
2005	**0.27**	**0.37**	**0**	**0.6**	**0.52**

Mathematics and Computer Sciences

Year	p_value income	IRC	p_value population	PRC	Adj. R2
1997	**0.023**	**0.15**	**0**	**0.12**	**0.53**
2005	**0.13**	**0.13**	**0**	**0.14**	**0.47**

Social and Behavioral Sciences

Year	p_value income	IRC	p_value population	PRC	Adj. R2
1997	**0.002**	**0.38**	**0**	**0.1**	**0.2**
2005	**0.002**	**0.45**	**0**	**0.11**	**0.18**

IRC is Income Regression Coefficient
PRC is Population Regression Coefficient

2005

By 2005 the regression results for the national income variable for mathematics and computer sciences for 2005 were not significant with a p-value of 0.13, a large change from the p-value of 0.023 in 1997. These results were similar to the ones seen for 181 nations, and it contrasts with life sciences, with the p-value for the national income variable from 1997 to 2005 becoming significant at p=0.039. For the year 2005 the national income variable remained significant for physical sciences at p=0.024. As with all other models, the national income variable for engineering was not significant, meaning that there is failure to reject the null hypothesis that foreign S&E doctoral attainment in engineering is not explained by differences in national income (that is, the results suggest that the income variable regression coefficient for engineering is zero). Finally, social and behavioral sciences is again distinguished from the other four S&E fields with its strongly significant p-value for national income and very low Adjusted R-squared value for both 1997 and 2005. Again note that the national income variable regression coefficients for all S&E fields were positive and largely unchanged from 1997 to 2005.

Discussion of Results

In summary, Model One testing was conducted with different types of disaggregated data on foreign S&E doctorates at American universities, to include variations in S&E field, total nations, and time period studied. Results suggest that controlling for population, national income effects vary according to S&E field, and that the behavior of students from China skewed the results for the entire group of 181 nations in 2005 in certain S&E fields, while no such skewing due to China was seen in testing for 1997. Increases in Chinese doctoral attainment after 1997 appeared to have affected the significance of the model's national income variable.

Specifically, testing results for 181 nations showed that controlling for population, the national income variable for the two fields of physical sciences and mathematics and computer sciences became not significant from 1997 to 2005, while social and behavioral sciences was largely unaffected by the growth in Chinese doctoral attainment. When excluding China from the model and testing for 180 nations, the p-values for physical sciences, life sciences and social and behavioral sciences were significant in 2005 (as opposed to being not significant in 2005 when including China). Therefore, it appears that China skewed the testing results in 2005 for physical sciences and life sciences, while not having the same affect for mathematics and computer sciences. As a result, when excluding China, there is failure to accept the null hypothesis that variation in foreign doctoral attainment in physical sciences, life sciences and social and behavioral sciences is not explained by differences in national income (in other words, there is failure to accept the null hypothesis that the regression coefficient for the national income variable is zero). Rather, results indicate that when excluding China in 2005, the national income variable regression coefficients are greater than zero, indicating that physical sciences, life sciences and social and behavioral sciences doctorates tended to be attained by students from higher income nations.

Finally, excluding China, South Korea and Taiwan from the model testing did not markedly change the statistical significance of the national income variable for physical sciences, life sciences, or social and behavioral sciences in 2005, when compared to testing results for 180 nations. That is, when comparing results for 180 nation testing (China excluded) to 178 nation testing (China, South Korea and Taiwan excluded) in 2005, the only real difference is an increased Adjusted R-squared value when excluding South Korea and Taiwan. Additionally, the positive regression coefficients for these three S&E fields remained so from 1997 to 2005. The indication here is that by 2005 South Korea and Taiwan had for the most part ceased to affect the significance of the model's national income variable. The only real outlier by the year 2005 appeared to be China.

CHAPTER 7

Research Questions and Hypothesis for Model Two

Previously, Model One was presented and tested for the effects of foreign student home nation income and population on doctoral attainment in each of the five S&E fields at American universities from 1994 to 2005. A second model, Model Two, is now presented and tested. This model tests for a relationship between growth in US government education-related R&D funding and growth in foreign S&E doctoral attainment based on differences in national income. The two variables tested in Model Two are considered as policy variables. The first policy variable is growth rate in US government R&D funding levels for each the five S&E fields. The second policy variable (associated with US immigration policy) is growth rate in foreign S&E doctoral counts by nation and by S&E field. The time period for testing is the same as in Model One, the years 1994 to 2005. When correlated, what is the strength of association between these two variables over this time period?

Model Two will build on the Model One discussion and analysis of foreign S&E doctoral attainment, to include the research questions and problems, conceptual framework, and methodology and data analysis previously presented. An assumption for Model Two is that R&D funding levels reflect US government S&E priorities, meaning more education-related government R&D funding to a certain S&E doctoral field is intended among other things to increase the number of doctorates being produced in that field (Salzman & Lowell 2007, Butz et al 2003, Goldman & Massy 2001). It is also assumed that the determination of annual US government R&D funding levels by S&E field is part of a public policy process influenced in varying degrees by the workings of the science community (Merton 1973, Kuhn 1996), by increasingly globalized social factors (Frank & Gabler 2006, Drori et al 2003), and by the American political process (Schneider & Ingram 1997).

The question to be addressed in Model Two is whether the S&E doctoral attainment choices by the foreign S&E doctoral students to whom the United States issued visas tended to track US government education-related R&D funding levels, and if there was variation in this association based on differences in the national income of the students' home nations during the time period 1994 to 2005. For example, assuming that increases in US government education-related R&D funding in physical sciences were intended in part to increase the number of physical sciences doctorates, were these R&D funding increases associated with increases in the number of physical sciences doctorates by students across all nations, or did the association vary according to the foreign students' home nation income? Again, Model Two tests for the strength of these associations in the form of correlation testing between growth in US government education-related R&D funding and growth in foreign S&E doctoral attainment by S&E field based on differences in national income, during the time period 1994 to 2005. As will be presented, in addition to being viewed as candidates attempting formal entry into the science community (Merton 1973), both US citizen and foreign S&E doctoral students are also viewed as trainees, to whom the US government offered incentives to remain in the S&E doctoral pipeline. As with Model One, the sole focus in Model Two is on foreign S&E doctoral students, and the question posed is whether there was variation in student behavior as to S&E doctoral degree choice associated with the students' home nation income.

Hypothesis for Model Two

The US government has indirectly subsidized education for foreign S&E doctorates at American universities in part through education-related R&D funding. It is theorized (null hypothesis) that from 1994 to 2005, annual variation in R&D funding growth in each of the five S&E fields is not associated with annual variation in foreign doctoral attainment growth by S&E field based on differences in home nation income. Therefore, the hypothesis for Model Two is:

H-null: There is no variation in the association between growth in annual foreign doctoral attainment and growth in annual US government education-related R&D funding for the time period 1994 to 2005 based on differences in national income, in each of the five S&E fields.

H-alternate: There is variation in the association between growth in annual foreign doctoral attainment and growth in annual US government education-related R&D funding for the time period 1994 to 2005, based on differences in national income, in one or all of the five S&E fields.

CHAPTER 8

Conceptual Framework for Model Two

Foreign S&E doctoral education, as with other types of education and training, may be viewed in terms of human capital (Becker 1962, Myers 1972), where migration is in part an,

> *"individual, spontaneous, and voluntary act, which rests on the comparison between the present situation of the actor and the expected net gain of moving, and results from a cost-benefit calculus. It follows that migrants will tend to go to the destination where a higher net return is expected, after pondering all the available alternatives. Insofar as it implies incurring certain costs in order to reap higher returns from one's labour, migration constitutes a form of investment in human capital" (Arango 2004 p. 18).*

Human capital is defined as a form of asset that yields income and other socially beneficial products over time, and is the composite of knowledge, skills, health and values that an individual possesses. Increases in the level of human capital allow individuals to act in new and more productive ways, and investment in education and training is an effective way to increase the level of human capital (Becker 1993, Piazza-Georgi 2002, Savvides and Stengos 2009). Increases in human capital are also associated with the production of *public goods* above and beyond those benefits accruing to the individual and therefore merits public policy interest (Romer 1990).[7] Technical

---

[7] Savvides & Stengos (2009) provides a useful overview of human capital and economic growth.

education in particular may merit government support due to the public benefits derived from innovation in science and technology (Solow 1956, Arrow 1962, Romer 1986, Romer 1990, Douglas 1948). Additionally, an important insight offered related to foreign S&E doctoral education is that knowledge has increasingly become a global public good, where "the efficient production and equitable use of global knowledge require collective action" (Stiglitz 1999, p. 321). This global perspective suggests that foreign S&E doctoral education in its capacity of knowledge creation does not exist in a US domestic vacuum, but rather has become a component in a global public goods creation regime that may call for increased policy coordination between nations. Certain types of human capital are theorized as being under produced by the market (Becker 1962), and this under production as an instance of market failure provides the rationale for government intervention (Wolf 1993). To better understand the under production of certain types of human capital, a distinction is made between *specific* and *general* training. Specific training is that training given by a firm to its employees that is beneficial only to that specific firm, such as training in that firm's production processes, product development, marketing or sales. The production of specific training is an example of a market efficient process, since the market determines the appropriate level of firm specific training based upon demand for the goods and services that the firm produces. As market demand changes, the level and type of specific training also change (Becker 1962). General training is different from specific training in that it can be used with equal effect by all firms with benefits also accruing to the public (Becker 1962). Examples of general training are the training of general practitioner doctors in a hospital, or the training of PhD biochemists at a university. These doctors' skills might be equally useful to all hospitals, and PhD biochemists' skills might be equally useful to many firms in the pharmaceutical industry or to government research laboratories.

Thus, the individual possesses human capital and the firm wants to use this human capital in order to make a profit, and both will tend to benefit from increases in this general training to the individual. However, firms may tend not to pay for general training in part because employees tend to leave before firms can recoup on their human capital investment (Becker 1962). The dilemma facing the firm stems from the exclusionary nature of human capital retained by the individual, where,

"A distinction can be made between the forms of human capital vested in the individual—education, experience, natural talents, including that for entrepreneurship—which are not easily transferable to other individuals, and the forms that have become public property: the stock of knowledge, found in books, media, blueprints and other documents accessible to all (albeit at a cost)" (Piazza-Georgi 2002).

An example of a firm tending not to pay for general training is seen in the following *Washington Post* article of December 7, 2006.

"Intel cut education subsidies for employees because it found that more people using the reimbursement program left the company than those who didn't…Intel spent $25 million last year on its reimbursement program, which 4,300 of its 90,000 employees worldwide participate in."

In this case, Intel's decision not to pay for its employees' general training might meet the criteria for market failure, where government intervention might be appropriate in order "to compensate for the tendency of the market, if it is not prodded, to produce insufficient output" (Wolf 1993). It should be noted that in the past, firms such as Intel have in fact funded general training for their employees, and some firms certainly continue to do so. However, general training may be at least under funded by firms. In the above example the Intel Corporation, its employees, and the public would appear to stand to gain from Intel's continued investment in general training. Intel could gain additional profits from increases in employee productivity, the employee could see an increase in wages related to increased productivity from this general training, and the public would gain from the associated creation of public goods in the form of accumulated knowledge and skills (Romer 1990). The problem however is that Intel is not inclined to fully fund this general training because other competing firms can "poach" employees trained at Intel's expense, resulting in a loss to Intel on its education investment. Again, this perceived market failure provides the US government with the rationale to intervene to promote increases in human capital in certain areas, to include S&E education, seen as being under produced.

US Government Intervention in Graduate S&E Education

Further, students tend not to invest fully in their own education, since they have an incentive to leave school early due to short-term benefits gained by foregoing more education and entering the labor market (Catsiapis 1987, Wolf 1993), and due to uncertainty over whether the types of training and education taken are related to the types of skills demanded in the future by the labor market (Becker 1993). However as previously discussed, the public goods created by education and training above and beyond those accrued to the individual provide the rational for governments to intervene.

In order to counter a student inclination to leave school and enter the labor market, the US government has a history of subsidizing education, to include graduate S&E education. US government intervention in the area of S&E graduate education increased dramatically in 1958 in the form of the National Defense Education Act, passed largely in response to the Soviet Union launch of Sputnik in 1957. The logic behind this legislation was that mathematics and science education was a critical component in the development of the technical workforce skills in short supply needed for a "war of the laboratory" (Anderson 2007). US Congress declared that "the security of the Nation requires the fullest development of the mental resources and technical skills of its young men and women…this requires programs that will give assurance that no student of ability will be denied an opportunity for higher education because of financial need" (DeVane 1965). In 1959 nearly 10,000 graduate fellowships and undergraduate loans were made by the US government. In 1963, $1.2 billion was allotted over a three year period for R&D related facilities construction, including those at universities. In 1964, another $1.8 billion was added, and the total outlays represented a massive increase in government support for university facilities and graduate education (DeVane 1965). Table 9 shows S&E doctoral attainment at American universities for selected years from 1960 to 2005 for both US citizen & permanent residents and foreign students. In 1960, there were 5,716 S&E doctorates attained by US citizens & permanent residents, compared to only 790 by foreign students. Ten years later in 1970 both populations had roughly tripled, to 17,137 for US citizens and permanent residents, compared to 2,142 for the foreign student population.

Table 9 S&E Doctorates at American Universities, 1960 to 2005

Year	Foreign Doctorate Totals	US Citizen & Permanent Resident Doctorate Totals	Total	Percent Foreign Share of Total
1960	790	5,716	6,506	12
1965	1,542	9,334	10,876	14
1970	2,142	17,137	19,279	11
1975	2,807	15,720	18,527	15
1980	2,842	14,901	17,743	16
1985	4,133	14,297	18,430	22
1990	7,215	16,059	23,274	31
1994	6,950	19,584	26,534	26
1995	7,573	19,697	27,270	28
1996	7,849	19,418	27,267	29
1997	7,483	19,051	26,534	28
1998	7,451	19,203	26,654	28
1999	7,465	18,320	25,785	29
2000	7,875	17,784	25,659	31
2001	8,006	16,885	24,891	32
2002	7,999	16,889	24,888	32
2003	8,644	17,061	25,705	34
2004	9,707	17,266	26,973	36
2005	11,109	17,865	28,974	38

Source: NSF/NIH/USED/HEH/USDA/NASA (2009)

The 1970s were a relatively static period in terms of S&E doctorate growth, with the US citizens and permanent resident population actually decreasing in number to 14,901 by 1980, while the foreign student population increased to 2,842. Note that from the year 1970 to 2005 there was little growth in annual numbers of S&E doctorates attained by US citizen & permanent residents. After falling to a low of 14,297 in 1985 and reaching a high of 19,637 in 1995, the total returned to approximately the 1970 level in 2005.

A big change seen in Table 9 is in the increase in foreign S&E doctoral attainment beginning in the year 1980. In 1980 there were 2,842 foreign S&E doctorates attained at American universities. By 2005 this number had almost quadrupled to 11,109.

From 1994 to 2005, the time period of this study, S&E doctoral attainment for US citizen & permanent residents versus foreign students went in opposite directions. S&E doctoral attainment for US citizen & permanent residents decreased from 19,584 in 1994 to 17,865 in 2005, while it increased from 6,950 in 1994 to 11,109 in 2005 for foreign students. During this time, the foreign share of total S&E doctorates at American universities increased from 26 percent in 1994 to 38 percent in 2005. Of particular note is the large increase in foreign S&E doctoral attainment after the year 2002. In 2002 there were 7,999 S&E doctorates attained by foreign students from the 181 nations. By 2005 this number had increased to 11,109, with the foreign share of the total increasing from 32 percent to 38 percent in just three years.

Current US Government Policy Towards the Promotion of S&E Education

The US government continues its "interventionist" S&E education policy (Anderson 2007), with current commitments to increase funding for S&E graduate education made in an environment of concern that the United States is losing its leadership edge (Galama & Hosek 2008). Continuity between past and present US policy goals with regard to S&E-related education is evidenced by a White House brief sheet on the President's speech to the National Academy of Sciences given on April 27, 2009.

*"Today, President Obama will speak before the Annual Meeting of the National Academy of Sciences, and discuss his plans to reinvigorate the American scientific enterprise through a bold commitment to basic and applied research, innovation, and education. Given the nature of the challenges the country faces in global economic competitiveness, energy, and health, the President will call for the U.S. to surpass its record investment in research and development, set in 1964 at the height of the space race, exceeding three percent of GDP. This goal would be met with both public and private investment. President Obama has already made science and technology a top priority: The Recovery Act includes $21.5 billion for research and development, the largest increase in our Nation's history...The President's FY10 budget includes sustained increases in basic research, $75 billion to make the research and experimentation tax credit permanent, and funding to triple the number of the National Science Foundation's graduate research fellowships…Between 2019 and 2016, the Administration's enacted and proposed budgets would add $42.6 billion to the 2008 budgets for these basic research agencies, with a special emphasis on encouraging high-risk, high-return research and supporting researchers at the beginning of their careers" (*White House 2009*).*

In short, the US government continues in its attempts to lower the opportunity costs of S&E doctoral education as the human capital component of its "high-risk, high-return research" strategy. Further, foreign students at American universities are viewed as no different from US citizens and permanent residents in the sense that all S&E doctoral students have access to similar levels of US government funded student financial aid during the years of their doctoral study (Goldman and Massy 2001).[8] The question asked in Model Two is whether foreign students from all nations respond to this financial aid in similar ways with respect to their S&E degree choice.

[8] For a general idea of the amount of financial aid available to foreign students, "Doctoral candidates in the sciences usually pay little or no tuition, and they receive a stipend for living expenses…In the 1990s, stipends ranged between $1,000 and $1,400 per month" (Goldman & Massy 2001)

Foreign S&E Doctoral Students as Trainees

Foreign S&E doctoral education may also be viewed in human capital terms, where "schools can be treated as a special type of firm and students as a special kind of trainee" (Becker 1962, pg. 26). In this way, university S&E doctoral education can be viewed as a type of training where,

"A school can be defined as an institution specializing in the production of training, as distinct from a firm that offers training in conjunction with the production of goods. Some schools, like those for barbers, specialize in one skill, while others, like universities, offer a large and diverse set" (Becker, 1962).

S&E doctorates are similar in some respects to employees receiving a lower on-the-job training wage during the training period (Becker 1962), where reduced wages and benefits in the shorter term are accepted by students in return for longer term payoffs associated with increases in human capital through S&E doctoral education and training. It is also theorized that S&E doctoral student behavior in the aggregate can be explained in terms of an interaction between market functioning and government intervention, where in the absence of subsidies to lower opportunity costs, the individual student will be less inclined to pursue S&E doctoral education even though it will most likely have longer term payoffs.

As discussed, firms tend not to pay for human capital investments to include S&E doctoral education, but it is theorized that the individual also will not tend to pay for this type of education. Why won't the student tend to fully pay for her or his own S&E doctoral education? One reason offered is that in a market of perfect information and no risk, the individual would indeed tend to invest in the optimum level of education so as to maximize on its total lifetime benefits (Catsiapis 1987). However, in the real world environment of imperfect information and considerable risk, students appear to perform a cost-benefit and risk analysis that tends to limit their individual educational investment. Students tend to factor in increased values of the shorter term opportunity costs (i.e., foregone income from not joining the labor market) associated with their own education decisions, while discounting the potentially greater longer term individual gains derived from the increased skills gained from an S&E doctorate (Catsiapis 1987, Wolf 1993). This type of student behavior results from uncertainty over the future value of an S&E doctorate, since an individual's investment in that specific field is subject to considerable risk and is extremely illiquid (Becker 1993). Therefore the S&E student has an increasing incentive to quit school prior to doctoral degree completion and enter the labor market as the value of his or her labor skills increase (Ehrenberg 1991, Catsiapis 1987). However, a decrease in the number of S&E doctorates who leave the education pipeline for economic reasons might be viewed by the government as a potential market failure resulting in decreased production of S&E-related public goods. Again, this potential for market failure provides governments with the rationale to intervene and to in effect persuade S&E doctoral students to stay in the laboratory and classrooms a few more years before entering the labor market.

The theorized workings of a national income variable as presented in Part One are also related to human capital theory and educational choices (Wolf 1993, Becker 1993, Ehrenberg 1991, Catsiapis 1987), where a form of the alternate hypothesis presented for Model Two is that foreign students from lower income nations who remain in the S&E doctoral pipeline at American universities will tend to be influenced more in their degree choice by US government education-related R&D funding compared to students from higher income nations. The idea here is that students from higher income nations who decide to pursue S&E doctorates at American universities may be less influenced in their degree field choice by US government financial aid. Other factors to include job prospects in the home nation labor market may have a greater influence on S&E degree choice, compared to students from lower income nations. Testing this hypothesis is especially relevant since the results from Model One indicated that during the time period 1994 to 2005, foreign S&E doctorates increasingly tended to come from lower income nations, notably from China. Did increases in growth in S&E doctoral attainment by students from lower income nations tend to track growth in R&D funding, since these students may have been more responsive to the shorter term economic incentives associated with student financial aid (Goldman & Massy 2001, Myers 1972)? In other words, might US government policy in the form of education-related R&D funding have a greater influence over S&E doctoral degree choice on students from lower income nations? Model Two will test for the existence of such a relationship in each of the five S&E fields.

CHAPTER 9

Methodology and Analysis for Model Two

Model Two tests for variation in foreign doctoral attainment in each of the five S&E fields associated with variation in US government education-related R&D funding, based on differences in the foreign students' home nation income. This is a temporal model with correlation testing using 1994 as the selected base year. Eleven observations will be correlated for each of the five S&E fields, one observation for each year-to-year change in S&E R&D funding from 1994 to 2005, with a five-year lag corresponding to per capita R&D funding. For example, the first observation to be tested for correlation is the rate of growth in R&D funding from 1989 to 1990, corresponding to the five-year lagged growth in doctoral attainment from 1994 to 1995. The eleventh observation is the rate of growth in R&D funding from 1999 to 2000, corresponding to the five-year lagged growth in doctoral attainment from 2004 to 2005. Why is there a five-year lag in the correlations between R&D funding and foreign S&E doctoral attainment rates? A five-year lag is used due to the assumption that it takes each student five years to complete an S&E doctorate, and the doctoral student's choice of S&E field is best associated with R&D funding levels in the first year of study.

Appendix F presents data for the R&D funding variable to be used in Model Two, "US Federal Government R&D Expenditures to Universities," by year, by S&E Field, in thousands of dollars from 1973 to 2000 (NSF 2008). A subset of this R&D data in Appendix F for the years 1989 to 2000 (five-year lag) will be used in the correlation testing. Note that the R&D funding increases during the broader time period from 1973 to 2000 vary across the five S&E fields. For example, the social and behavioral sciences show the smallest factor increase in funding (4.7), from $139.3 million in the year 1973 to $661.2 million in the year 2000, while mathematics and computer sciences show the largest factor increase in funding (16.1), from $49.4 million in the year 1973 to $792.9 million in the year 2000.

Testing will be conducted by the four national income quartiles, the same quartiles that were presented in Model One. To test for variation in associations between R&D funding and doctoral attainment by S&E field based on differences in nation income, each correlation test (one for each of the five S&E fields) will divide the selected 181 foreign nations into four quartiles based on per capita gross national income (GNI). Again, the format is the same as that presented in Appendix B for Model One:

<u>Quartile One:</u> 46 nations with per capita GNI greater than $7,500

<u>Quartile Two:</u> 45 nations with per capita GNI less than $7,500 and greater than $1,750

<u>Quartile Three:</u> 45 nations with per capita GNI less than $1,750 and greater than $550

<u>Quartile Four:</u> 45 nations with per capita GNI less than $550

Are the correlation test results similar for each of the four national income quartiles for each of the five S&E fields?

Assumptions and Limitations for Model Two Testing

It is assumed that all foreign S&E doctoral students from a given nation carry the same preferences and are presented with the same incentives to pursue a specific S&E degree when matriculating at an American university. However, this assumption might not be entirely correct since there may be variation in preferences, to include whether the foreign student intends to stay in the United States upon doctoral completion or whether the student intends to return home. In short, "we should leave open the possibility that causality runs from non-return to course choice rather than vice versa" (Myers 1972 p. 336). In particular, differences in these preferences might be the greatest for students from some lower income nations like China and India who had greater "intend to stay rates" than students from higher income nations (Finn 2005). To the extent that they are present, Model Two will fail to capture differences in S&E doctoral preferences, for example, between students from China who intend to stay in the United States and those who intend to return to China.

An added and related factor not included in Model Two testing is the influence of foreign government financial aid to foreign S&E doctoral students. As discussed in Model One, foreign government intervention was offered as a potential reason for the large numbers of South Korean and Taiwanese S&E doctorates, and it also apples to Model Two. For example, a certain foreign nation might both fund the doctoral education of its citizens in predetermined S&E fields at American universities (in S&E fields decided upon by the foreign government) and offer them related jobs in the home nation upon doctoral degree attainment (Myers 1972). May differences in foreign government intervention result in differences in the types of S&E doctorates attained? Is there more intervention by governments from higher or lower income nations? Results from a previous study support the existence of a foreign nation funding variable, where differences in behavior were found between "sponsored students," meaning those foreign students at American universities receiving financial support from the home nation, and "unsponsored" students. The sponsored students had a higher return rate to home nations than unsponsored ones (COIMT 1970). Might there have also been variation with respect to their degree choices between those receiving and not receiving home nation financial aid and/or home nation job offers upon doctoral degree completion? This variable is not included in Model Two and the workings of this variable are not known, since data on foreign government funding is not available.

However, have foreign nations come to face the same dilemma as the Intel Corporation as previously discussed, where foreign doctorates may "defect" from the party paying for the education (i.e., their home nation governments) and make choices based upon individual preferences, to include S&E doctoral degree choice and whether to stay and work in the United States? As a result of this dilemma of students defecting just as employees defected from Intel, do foreign governments tend to reach the same conclusion as Intel and tend not to fund S&E doctoral education for their citizens studying at American universities? Therefore, while Model Two will not test for factors related to foreign government intervention, these effects may be mitigated somewhat by other factors causing foreign governments to be less involved in the S&E degree choices of their citizens at American universities.

Finally, Model Two is viewed as being less statistically robust than Model One. While Model One initially uses 181 observations (one for each nation) for multivariate regression testing, Model Two uses a simple correlation analysis with only eleven observations, one for the rates of growth in the two variables for each year. While the number of observations may be increased by expanding the time period from 1994 to 2005 to the time period 1980 to 2005 for example, it must first be ascertained that the dynamics of highly-skilled migration for foreign S&E doctoral attainment during this expanded time period did not change. Previous results suggest that foreign S&E doctoral attainment patterns did in fact change, and expanding the time period to be studied to before 1994 is problematic, since Cold War–related factors restricting highly-skilled migration may have ended in the late 1980s (Hamilton & Perry 2008). As a result, expanding the time period for foreign S&E doctoral attainment to include the 1980s would have little justification beyond gaining more observations for correlation testing. More generally, creating one model to explain highly-skilled migration over a long period of time is problematic, due in part to the possibility that, "political factors are nowadays much more influential than differential wages in determining mobility or immobility" (Arango 2004 p. 20). Therefore, while Model One regression testing for 181 (and 179) nations returned statistics which showed the significance of the national income variable for certain S&E fields at $p<0.05$, the scope of Model Two correlation testing is limited to only 11 observations. Model Two is again viewed as a test for how foreign S&E doctoral attainment tracks US government R&D funding, and if there are differences in strengths of associations between students from higher income and lower income nations.

Model Two Testing Results

Model Two testing results are shown in Table 10. The discussion first focuses on the variation in the strengths of association between the four national income quartiles for each of the five S&E fields.

Table 10 Model Two Testing Results

Correlation Results	Physical Sciences	Life Sciences	Engineering	Mathematics and computer sciences	Social and behavioral sciences
Quartile 1	-0.03	0.29	0.22	-0.31	-0.14
Quartile 2	0.25	-0.33	0.09	0.20	0.12
Quartile 3	0.30	0.25	0.06	0.20	-0.08
Quartile 4	0.74	0.59	0.35	0.34	0.31

A general pattern seen in the results of correlation testing is the increasing strengths of association tracking with decreases in national incomes. The clearest case of this tracking is physical sciences. For the highest income quartile (Quartile One), the association between annual R&D funding growth and annual foreign doctoral attainment growth is weak and negative (-0.03). However, for students from the groups of lower income nations, the strength of this association becomes positive and increases, from the Quartile Two nations (0.25), to the Quartile Three nations (0.30), and finally to the lowest income group of Quartile Four nations (0.74). A positive association indicates that increases in R&D funding are associated with increases in S&E doctoral attainment in the particular field. In other words, changes in physical sciences doctoral attainment by students from the lower income nations tended to more closely track changes in education-related R&D funding compared to students from higher income nations.

A similar result is seen with mathematics and computer sciences. For the highest income quartile (Quartile One), the association between annual R&D funding growth and annual foreign doctoral attainment growth is negative (-0.31). However, for students from the groups of lower income nations, the strength of this association becomes positive and increases, from the Quartile Two and Three nations (both 0.20) to the lowest income group of Quartile Four nations (0.34). This positive association again indicates that increases in R&D funding are associated with increases in S&E doctoral attainment, although the associations for mathematics and computer sciences are weaker than for physical sciences.

This type of pattern is also seen in the other three S&E fields, although there are differences in the strengths of associations across the four national income quartiles. For example, in life sciences students from the group of Quartile Four nations showed a relatively strong association between annual R&D funding growth and annual foreign doctoral attainment growth (0.59), similar to the strong association seen in physical sciences. However, the increasing strengths of association did not track with decreases in national incomes for life sciences, as seen by the value for Quartile One (0.29) being positive and stronger than the value for Quartile Two (-0.33). Engineering was similar to life sciences in that students from the group of Quartile Four nations showed a relatively strong association between annual R&D funding growth and annual foreign doctoral attainment growth (0.35). However, the increasing strengths of association did not track with decreases in national incomes for engineering, as seen by the value for Quartile One (0.22) being stronger than the values for Quartile Two (0.09) and Quartile Three (0.06).

Lastly, social and behavioral sciences was again similar to the other four S&E fields in that students from the group of Quartile Four nations showed a relatively strong association between annual variation in R&D funding growth and annual variation in foreign doctoral attainment growth (0.31). However, associations for the other three national income quartiles are weakly positive or negative. Thus there is failure to accept the null hypothesis that there is no variation in the association between growth in annual foreign doctoral attainment and growth in annual US government education-related R&D funding for the time period 1994 to 2005 based on differences in national income, in each of the five S&E fields. As a result, there is failure to reject the alternate hypothesis that there is variation in the association between growth in annual foreign doctoral attainment and growth in annual US government education-related R&D funding for the time period

1994 to 2005, based on differences in national income, in one or all of the five S&E fields.

CHAPTER 10

Concluding Remarks

The main conclusion from the empirical findings for Models One and Two is that data on foreign S&E doctoral attainment must be disaggregated by S&E field, by time period and by nation to be of research value. Analysis of S&E doctoral attainment data for the time period 1994 to 2005 and for national groupings in the aggregate was misleading, since highly-skilled migration patterns appeared to have changed during this twelve-year time period.

Highly-skilled migration patterns also varied by nation and by individual S&E field. The changes with the most impact came from China, South Korea and Taiwan, since these three nations comprised a substantial number of the total S&E doctorates attained during this time period. Various cases of misleading aggregate analysis appearing in the testing results can be considered as instances of *"Simpson's Paradox"* (Wonnacott & Wonnacott 1987), where the important student attributes of the disaggregated parts (i.e., South Korea and Taiwan in the 1990s, China after the year 2002, and the lowest income nations during the entire time period), were not apparent in the aggregate results.

Model One testing results for the individual years 1997 and 2005 showed that there was variation in foreign S&E doctoral attainment at American universities during the 1994 to 2005 time period that was not seen in the first two regression models that only tested the aggregated data for the entire time period 1994 to 2005. Testing results from the revised model indicated that in 2005, highly-skilled migration patterns had changed from that in 1997 such that the national income variable was not significant for all fields except for social and behavioral sciences.

However, further disaggregation excluding China from Model One testing indicated that China was the apparent cause of a not significant national income variable. In other words, excluding for China, in 2005 foreign doctorates in physical sciences, life sciences and social and behavioral sciences tended to be attained by students from higher income nations, controlling for population, as had been the case earlier in the time period. Engineering continued to be different from the other four S&E fields (its national income variable regression coefficient remained zero no matter how data was disaggregated by nation or by time period).[9] There are two major policy-related findings resulting from Model One analysis.

The first finding is that virtually all growth in foreign doctoral attainment in physical sciences, life sciences, engineering, and mathematics and computer sciences from 1994 to 2005 came from Chinese students, and that this growth was most pronounced after the

[9] Future research will disaggregate engineering into subfields (e.g. civil, mechanical, electrical) and retest using Model One methodology. Is the national income variable significant for certain subfields?

year 2001. In short, whereas the foreign student populations from South Korea and Taiwan were the outliers in 1994, they had largely been displaced in 2005 by Chinese students. From the US public policy perspective, to the extent that growth in foreign S&E doctoral attainment is an issue in regards to its costs and benefits, the appropriate policy focus should shift more specifically towards the growth in Chinese S&E doctoral attainment.

The second finding is that with the exception of China and India, foreign doctoral students from the lowest income nations of the world in all five S&E fields were under represented on American campuses from 1994 to 2005. To the extent that attracting more of these students to American universities is a US public policy goal, greater involvement by the government to better support American university recruiting efforts appears to be needed. One area for future research that may aid in these recruitment efforts may be in studying the S&E doctoral student migration networks for China, South Korea and Taiwan in particular. Can the high S&E doctoral attainment rates by students from these three nations be best explained by either the existence of government intervention, a self-perpetuating informal social migration network, or a combination of both that has evolved over time?

Results from Model Two testing complement the findings in Model One, where changes in S&E doctoral attainment by students from the lower income nations tended to more closely track changes in education-related R&D funding compared to students from higher income nations. These results suggest that to the extent the US government desires to increase foreign doctoral attainment in specific S&E fields, students from lower income nations might have a greater tendency to "chase" the education-related R&D dollars in the targeted S&E fields. Students from higher income nations appeared to have little or no tendency to track R&D funding during this time period. One hypothesis for why students from higher income nations tend not to "chase" education-related R&D dollars is that these students might be more likely both to have higher family income to finance their graduate educations and to receive financial aid from their own (higher income) nations. This finding also suggests that research opportunities and research-related jobs may be especially important for students from lower income nations. That is, education-related R&D funding may produce both more dissertation opportunities and more jobs for graduate students, and these factors may be especially important in helping doctoral students from lower income nations complete their doctoral degrees.[10]

Finally, foreign S&E doctoral attainment at American universities is only one piece of a global puzzle. How to characterize the larger global dynamic of highly-skilled migration and S&E doctoral attainment? Are the same or different trends seen in other nations? Further, to the extent that the public goods created by S&E doctoral education are global, a case can be made that "the efficient production and equitable use of global knowledge require collective action (Stiglitz 1999, p. 321)" by the governments of nations both

[10] Thanks to Dr. James Hosek for this insight.

educating and supplying these students. The conclusion reached here echoes the 2008 RAND report quoted earlier that,

"We have encountered additional areas for which substantial knowledge appears to be lacking and that may benefit from further research," to include "factors affecting the recruiting and retention of foreign S&E talent (i.e., a study on the decision of foreign students to do graduate and undergraduate work in the United States" (Galama and Hosek 2008).

Research on the "decision of foreign students to do graduate and undergraduate work in the United States" (Galama and Hosek 2008) can therefore be expanded to the global level. For example, if there is a decrease in foreign S&E degree attainment at American universities by students from a given nation, did these potential graduates migrate to another nation's university (e.g. Canada or Australia), did they stay home to pursue education, or did they leave the S&E educational pipeline entirely and enter the labor market? Tracking both citizen and foreign S&E degree attainment on a nation by nation basis will help fill in the pieces of this global puzzle, and the initial focus should be on characterizing and comparing S&E attainment in the higher income nations like the United Kingdom, Canada, Australia, Japan and European nations. The reason for first targeting these higher income nations for study is that they tend to have the financial resources to better support S&E education compared to lower income nations. With respect to foreign S&E doctoral attainment at universities in nations other than the United States, are these nations' foreign student populations also increasingly coming from China? Future research would include building a worldwide migration matrix of those students attaining their S&E doctorates abroad. With an expanded focus on foreign S&E doctoral attainment at the global level, this type of highly-skilled migration system and the global public goods it produces may be better understood, allowing for improved public policy through better coordination between governments and other related national and transnational organizations.

Appendix A

Foreign S&E Doctoral Attainment, By Field, 1978 to 2005

Year	Phys. Sci	% Total	Life Sci	% Total	Engin.	% Total	Mathem CS	% Total	Soc Behav	% Total	Total
1978	503	19	617	23	798	30	198	7	530	20	2,646
1979	470	18	634	24	822	31	167	6	531	20	2,624
1980	516	18	664	23	919	32	214	8	529	19	2,842
1981	573	19	694	22	987	32	246	8	592	19	3,092
1982	606	19	688	21	1,106	34	244	7	613	19	3,257
1983	653	18	740	21	1,206	34	327	9	624	18	3,550
1984	694	18	835	21	1,331	34	310	8	746	19	3,916
1985	798	19	838	20	1,427	35	369	9	701	17	4,133
1986	859	20	833	20	1,419	33	432	10	709	17	4,252
1987	1,022	21	957	20	1,668	34	474	10	746	15	4,867
1988	950	18	1,083	21	1,860	36	494	9	841	16	5,228
1989	1,115	19	1,258	21	2,064	34	609	10	948	16	5,994
1990	1,380	19	1,545	21	2,494	35	785	11	1,011	14	7,215
1991	1,551	20	1,762	22	2,652	33	871	11	1,116	14	7,952
1992	1,500	18	1,916	23	2,841	34	862	10	1,184	14	8,303
1993	1,460	18	1,912	23	2,781	34	860	10	1,192	15	8,205
1994	1,073	15	1,643	24	2,474	36	719	10	1,041	15	6,950
1995	1,221	16	1,805	24	2,604	34	785	10	1,158	15	7,573
1996	1,326	17	2,027	26	2,681	34	793	10	1,022	13	7,849
1997	1,288	17	1,944	26	2,481	33	740	10	1,030	14	7,483
1998	1,324	18	1,984	27	2,316	31	783	11	1,044	14	7,451
1999	1,315	18	2,083	28	2,281	31	763	10	1,023	14	7,465
2000	1,357	17	2,001	25	2,557	32	793	10	1,167	15	7,875
2001	1,353	17	1,978	25	2,775	35	779	10	1,121	14	8,006
2002	1,352	17	2,048	26	2,680	34	783	10	1,136	14	7,999
2003	1,447	17	2,103	24	2,991	35	867	10	1,236	14	8,644
2004	1,623	17	2,218	23	3,468	36	1,064	11	1,334	14	9,707
2005	1,847	17	2,496	22	3,964	36	1,357	12	1,445	13	11,109
Factor Increase 1978 to 2005	3.7		4.0		5.0		6.9		2.7		4.2

Source: NSF/NIH/USED/HEH/USDA/NASA (2009)

Appendix B

Foreign S&E Doctoral Attainment Data by Nation, By National Income Quartile

COUNTRY	Total S&E Doctorates 1994_2005	Population (Thousands)	per capita GNI (US$)
Quartile One			
Bermuda	<25	59	42,375
Luxembourg	<25	393	40,074
Switzerland	238	6,995	38,841
Japan	1,827	124,329	33,841
Norway	115	4,286	31,805
Denmark	138	5,171	30,088
Sweden	179	8,719	27,687
Iceland	158	266	26,429
Germany	1,828	80,598	25,706
Austria	161	7,915	25,031
Belgium	195	10,046	24,307
San Marino	<25	25	24,225
Netherlands	381	15,460	23,827
France	839	58,859	23,518
Monaco	<25	30	23,518
Finland	123	5,041	22,987
Hong Kong	629	5,830	22,015
Singapore	389	3,236	20,591
United Kingdom	646	57,866	20,560
Canada	3,074	28,545	20,206
Italy	1,042	56,841	20,014
Australia	436	17,419	19,777
British Virgin Islands	<25	17	18,973
UAE	99	2,056	18,795
Greenland	<25	55	18,420
Qatar	<25	476	17,827
Ireland	161	3,636	16,953
Israel	515	4,822	16,044
Aruba	<25	69	15,997
Kuwait	182	1,418	15,907
French Polynesia	<25	212	15,551
Brunei	<25	266	15,080
Spain	641	39,549	14,417
New Zealand	236	3,494	13,622
Taiwan	8,242	20,855	13,510
Netherlands Antilles	<25	192	13,387
Bahamas	<25	264	12,638
Cyprus	226	707	12,274
South Korea	10,500	43,837	12,234
Greece	1,126	10,325	11,636

Portugal	293	9,928	10,237
Bahrain	31	529	9,735
Malta	<25	380	8,950
Saudi Arabia	745	16,946	7,986
St Barthelemy	<25	6	7,501
St Kitts	<25	41	7,501

Quartile Two

Antigua & Barbuda	<25	65	7,134
Argentina	699	33,967	7,001
Anguilla	<25	9	6,982
Barbados	28	265	6,900
Oman	42	1,989	6,332
Seychelles	<25	72	6,319
Libya	<25	4,365	6,185
Uruguay	143	3,153	5,217
Czechoslovakia	256	10,316	4,644
St Lucia	<25	141	4,300
Gabon	<25	986	4,189
Trinidad	143	1,264	4,177
Chile	403	13,574	4,124
Mexico	1,912	88,111	4,067
Hungary	302	10,349	3,944
Brazil	1,667	156,032	3,687
Malaysia	563	18,325	3,548
Estonia	31	1,529	3,445
Mauritius	<25	1,085	3,298
Poland	375	38,371	3,274
Lebanon	367	3,222	3,255
Venezuela	579	20,246	3,199
South Africa	346	40,091	3,173
Panama	67	2,489	3,122
Costa Rica	173	3,173	3,093
Dominica	<25	70	3,048
Grenada	<25	91	2,857
Moldova	<25	4,438	2,800
Turkey	2,750	58,731	2,775
Botswana	33	1,345	2,671
Russia	1,663	148,340	2,652
Latvia	25	2,616	2,585
Cuba	<25	10,692	2,560
Belize	<25	201	2,540
Lithuania	55	3,700	2,454
Fiji	<25	751	2,258
Thailand	2,358	56,667	2,198
Jamaica	115	2,378	2,126
Micronesia	<25	105	1,997
Colombia	616	34,314	1,954
Namibia	<25	1,553	1,929
Dominican Republic	53	7,360	1,894
Peru	291	22,522	1,864

Surinam	<25	397	1,828
Tunisia	138	8,527	1,809

Quartile Three

Tonga	<25	92	1,718
Algeria	59	26,298	1,683
Iran	792	59,999	1,678
Maldives	<25	238	1,559
El Salvador	<25	5,275	1,554
Byelarus	52	10,228	1,492
Jordan	751	3,867	1,484
Ecuador	131	10,544	1,481
Paraguay	<25	4,493	1,464
Romania	1,070	22,797	1,458
Kazakhstan	38	16,542	1,418
Palestine	82	1,019	1,415
Bulgaria	410	8,442	1,380
Swaziland	<25	962	1,316
Morocco	121	25,850	1,250
Guatemala	63	9,367	1,235
Egypt	1,000	59,394	1,141
Ukraine	331	51,867	1,110
Western Sahara	29	236	1,000
Syria	87	13,219	982
Philippines	550	67,978	975
Bolivia	71	6,893	874
Kiribati	<25	75	831
Honduras	55	5,077	828
Papua New Guinea	<25	4,028	789
Albania	45	3,326	787
Dijibouti	<25	384	787
Georgia	36	5,355	784
Equitorial Guinea	<25	392	778
Indonesia	625	188,108	769
Ivory Coast	50	13,422	750
Lesotho	<25	1,802	720
Congo	<25	43,955	716
Sri Lanka	514	17,756	706
Turkmenistan	<25	3,830	701
Tanzania	66	26,767	700
Cameroon	94	12,575	699
Guyana	31	747	670
Nicaragua	30	4,020	638
Uzbekistan	<25	21,610	634
China	23,375	1,177,482	621
Azerbaijan	<25	7,459	600
Zimbabwe	99	10,720	600
Senegal	34	8,517	592
Pakistan	642	120,098	569

Quartile Four

Mauritania	<25	2,043	565

Iraq	40	17,862	559
Angola	<25	8,742	540
Bhutan	<25	602	531
North Korea	<25	21,073	524
Mongolia	<25	2,318	517
Armenia	46	3,378	493
Guinea	<25	6,801	467
Kenya	310	25,019	426
India	10,836	869,090	379
Anjouan	<25	454	370
Ghana	222	16,302	361
Kyrgyzstan	<25	4,495	358
Sudan	69	27,851	351
Zambia	28	8,445	341
Central African Republic	<25	3,267	339
Yemen	<25	14,395	338
Haiti	<25	6,523	335
Benin	<25	5,010	330
Gambia	<25	1,025	319
Togo	<25	3,748	315
Tajikistan	18	5,500	302
Bangladesh	501	116,561	302
Laos	<25	4,846	302
Mali	34	8,418	301
Burkina Faso	<25	8,935	283
Nigeria	200	101,625	282
Rwanda	<25	7,271	266
Vietnam	94	69,941	254
Madagascar	<25	12,357	232
Uganda	94	18,729	230
Sierra Leone	26	4,267	226
Chad	<25	6,263	221
Cambodia	<25	10,123	215
Niger	<25	8,339	213
Nepal	165	20,033	196
Somalia	<25	6,116	190
Guinea-Bissau	<25	1,051	189
Mozambique	<25	13,180	189
Afghanistan	<25	16,318	179
Malawi	42	10,294	166
Burma	<25	40,133	158
Burundi	<25	5,809	156
Ethiopia	222	51,673	144
Liberia	<25	1,913	102

Appendix C

Presentation of S&E Doctoral Attainment from 1994 to 2005 by National Income Quartiles, by S&E field

1. Quartile One

a. Physical Sciences

Physical Sciences Quartile One

Nation	Total Doctorates	Percent of Total
South Korea	1,475	26.8%
Taiwan	943	17.2%
Canada	529	9.6%
Germany	508	9.2%
Japan	244	4.4%
Italy	244	4.4%
France	235	4.3%
Greece	198	3.6%
United Kingdom	177	3.2%
Hong Kong	140	2.5%
Spain	91	1.7%
Netherlands	77	1.4%
Israel	63	1.1%
Saudi Arabia	62	1.1%
Australia	57	1.0%
Switzerland	48	0.9%
Austria	40	0.7%
New Zealand	39	0.7%
Singapore	36	0.7%
Portugal	36	0.7%
Denmark	32	0.6%
Sweden	31	0.6%
Ireland	31	0.6%
Norway	30	0.5%
Iceland	28	0.5%
Total 25 nations	5,394	98.2%
Total 46 nations	5,494	

b. Life Sciences

Life Sciences Quartile One

Nation	Total Doctorates	Percent of Total
Taiwan	2,157	27.2%
South Korea	1,993	25.1%
Canada	989	12.4%
Germany	368	4.6%
Japan	333	4.2%
Greece	179	2.3%
United Kingdom	175	2.2%
France	164	2.1%
Spain	164	2.1%
Saudi Arabia	162	2.0%
Hong Kong	136	1.7%
Italy	130	1.6%
Netherlands	126	1.6%
Australia	119	1.5%
Singapore	86	1.1%
Israel	80	1.0%
New Zealand	68	0.9%
Portugal	65	0.8%
Switzerland	57	0.7%
Cyprus	46	0.6%
Sweden	42	0.5%
Belgium	41	0.5%
Iceland	40	0.5%
Kuwait	35	0.4%
Finland	32	0.4%
Denmark	30	0.4%
Ireland	30	0.4%
Austria	29	0.4%
Total 28 nations	7,876	99.1%
Total 46 nations	7,944	

c. Engineering

Engineering Quartile One

Nation	Total Doctorates	Percent of Total
South Korea	4,072	36.5%
Taiwan	3,516	31.5%
Canada	438	3.9%
Greece	402	3.6%
Japan	345	3.1%
Germany	328	2.9%
Saudi Arabia	296	2.7%
France	244	2.2%
Italy	194	1.7%
Hong Kong	143	1.3%
Singapore	121	1.1%
Spain	116	1.0%
Kuwait	99	0.9%
Israel	95	0.9%
Cyprus	81	0.7%
Netherlands	69	0.6%
United Kingdom	65	0.6%
Australia	65	0.6%
Portugal	61	0.5%
Belgium	56	0.5%
Switzerland	49	0.4%
Sweden	45	0.4%
UAE	38	0.3%
Norway	37	0.3%
New Zealand	35	0.3%
Austria	25	0.2%
Total 36 nations	11035	98.9%
Total 46 nations	11156	

d. Mathematics & Computer Sciences

Mathematics & Computer Sciences Quartile One

Nation	Total Doctorates	Percent of Total
South Korea	962	26.0%
Taiwan	707	19.1%
Germany	276	7.5%
Canada	260	7.0%
Greece	214	5.8%
Italy	148	4.0%
Japan	95	2.6%
Hong Kong	94	2.5%
United Kingdom	91	2.5%
Saudi Arabia	89	2.4%
Israel	82	2.2%
France	66	1.8%
Australia	66	1.8%
Spain	65	1.8%
Portugal	57	1.5%
Singapore	53	1.4%
New Zealand	45	1.2%
Switzerland	42	1.1%
Cyprus	38	1.0%
Ireland	32	0.9%
Austria	30	0.8%
Netherlands	29	0.8%
Denmark	26	0.7%
Total 23 nations	3,567	96.4%
Total 46 nations	3,699	

e. Social & Behavioral Sciences

Social & Behavioral Sciences
Quartile One

Nation	Total Doctorates	Percent of Total
South Korea	1,998	27.8%
Taiwan	919	12.8%
Canada	858	11.9%
Japan	810	11.3%
Germany	348	4.8%
Italy	326	4.5%
Spain	205	2.8%
Israel	195	2.7%
United Kingdom	138	1.9%
Saudi Arabia	136	1.9%
Greece	133	1.8%
France	130	1.8%
Australia	129	1.8%
Hong Kong	116	1.6%
Singapore	93	1.3%
Netherlands	80	1.1%
Portugal	74	1.0%
Belgium	57	0.8%
New Zealand	49	0.7%
Iceland	46	0.6%
Ireland	45	0.6%
Switzerland	42	0.6%
Sweden	41	0.6%
Cyprus	40	0.6%
Austria	37	0.5%
Finland	36	0.5%
Denmark	34	0.5%
Kuwait	25	0.3%
Total 28 nations	7,140	99.2%
Total 46 nations	7,198	

2. Quartile Two

a. Physical Sciences

Physical Sciences Quartile Two

Nation	Total Doctorates	Percent of Total
Russia	708	28.5%
Turkey	293	11.8%
Mexico	219	8.8%
Thailand	192	7.7%
Brazil	148	6.0%
Poland	109	4.4%
Argentina	98	3.9%
Hungary	85	3.4%
Colombia	80	3.2%
Czechoslovakia	72	2.9%
Malaysia	69	2.8%
Venezuela	61	2.5%
Lebanon	50	2.0%
South Africa	43	1.7%
Chile	39	1.6%
Peru	39	1.6%
Trinidad	26	1.0%
Total 17 nations	2,331	93.9%
Total 45 nations	2,483	

b. Life Sciences

Life Sciences Quartile Two

Nation	Total Doctorates	Percent of Total
Thailand	791	17.6%
Mexico	688	15.3%
Brazil	590	13.1%
Turkey	443	9.9%
Russia	234	5.2%
Argentina	227	5.1%
Colombia	206	4.6%
Venezuela	167	3.7%
Chile	143	3.2%
Malaysia	142	3.2%
South Africa	112	2.5%
Lebanon	104	2.3%

Peru	73	1.6%
Costa Rica	70	1.6%
Poland	61	1.4%
Uruguay	59	1.3%
Czechoslovakia	57	1.3%
Hungary	56	1.2%
Trinidad	50	1.1%
Jamaica	46	1.0%
Total 20 nations	4,319	96.2%
Total 45 nations	4,489	

c. Engineering

Engineering Quartile Two

Nation	Total Doctorates	Percent of Total
Turkey	1,287	26.3%
Thailand	975	19.9%
Mexico	482	9.8%
Brazil	439	9.0%
Russia	260	5.3%
Malaysia	196	4.0%
Venezuela	188	3.8%
Colombia	155	3.2%
Lebanon	151	3.1%
Argentina	110	2.2%
Tunisia	86	1.8%
Chile	83	1.7%
South Africa	81	1.7%
Peru	78	1.6%
Poland	60	1.2%
Czechoslovakia	49	1.0%
Hungary	41	0.8%
Trinidad	30	0.6%
Costa Rica	25	0.5%
Total 19 nations	4,776	97.5%
Total 45 nations	4,898	

d. Mathematics & Computer Sciences

Mathematics & Computer Sciences Quartile Two Nation	Total Doctorates	Percent of Total
Russia	296	17.3%
Turkey	283	16.6%
Brazil	185	10.8%
Mexico	166	9.7%
Thailand	128	7.5%
Poland	97	5.7%
Hungary	79	4.6%
Venezuela	71	4.2%
Argentina	64	3.7%
Colombia	60	3.5%
Malaysia	45	2.6%
Czechoslovakia	44	2.6%
Chile	31	1.8%
Lebanon	25	1.5%
South Africa	25	1.5%
Total 15 nations	1,599	93.7%
Total 45 nations	1,707	

e. Social & Behavioral Sciences

Social & Behavioral Sciences Quartile Two Nation	Total Doctorates	Percent of Total
Turkey	444	16.2%
Mexico	357	13.1%
Brazil	305	11.2%
Thailand	272	9.9%
Argentina	200	7.3%
Russia	165	6.0%
Colombia	115	4.2%
Malaysia	111	4.1%
Chile	107	3.9%
Venezuela	92	3.4%
Peru	87	3.2%
South Africa	85	3.1%
Poland	48	1.8%
Hungary	41	1.5%
Uruguay	39	1.4%
Costa Rica	39	1.4%

Lebanon	37	1.4%
Czechoslovakia	34	1.2%
Trinidad	27	1.0%
Total 19 nations	2,605	95.3%
Total 45 nations	2,734	

3. Quartile Three

a. Physical Sciences

Physical Sciences Quartile Three

Nation	Total Doctorates	Percent of Total
China	4,950	76.7%
Romania	324	5.0%
Sri Lanka	164	2.5%
Philippines	151	2.3%
Bulgaria	130	2.0%
Ukraine	128	2.0%
Iran	107	1.7%
Jordan	91	1.4%
Pakistan	81	1.3%
Egypt	69	1.1%
Indonesia	55	0.9%
Byelarus	26	0.4%
Total 12 nations	6,276	97.2%
Total 45 nations	6,457	

b. Life Sciences

Life Sciences Quartile Three

Nation	Total Doctorates	Percent of Total
China	6,443	77.6%
Pakistan	220	2.6%
Egypt	190	2.3%
Jordan	186	2.2%
Philippines	181	2.2%
Indonesia	149	1.8%
Sri Lanka	133	1.6%
Romania	122	1.5%
Iran	112	1.3%
Bulgaria	60	0.7%
Ecuador	56	0.7%

Ukraine	54	0.7%
Zimbabwe	50	0.6%
Cameroon	41	0.5%
Morocco	40	0.5%
Honduras	37	0.4%
Total 16 nations	8,074	97.3%
Total 45 nations	8,302	

c. Engineering

Engineering Quartile Three

Nation	Total Doctorates	Percent of Total
China	8,566	76.0%
Egypt	592	5.3%
Iran	467	4.1%
Jordan	332	2.9%
Indonesia	256	2.3%
Pakistan	238	2.1%
Romania	208	1.8%
Sri Lanka	113	1.0%
Philippines	78	0.7%
Ukraine	54	0.5%
Bulgaria	49	0.4%
Syria	47	0.4%
Palestine	39	0.3%
Morocco	33	0.3%
Ecuador	30	0.3%
Total 15 nations	11,102	98.5%
Total 45 nations	11,267	

d. Mathematics & Computer Sciences

Mathematics & Computer Sciences Quartile Three

Nation	Total Doctorates	Percent of Total
China	2,275	69.3%
Romania	355	10.8%
Bulgaria	98	3.0%
Iran	79	2.4%
Jordan	75	2.3%
Egypt	74	2.3%
Ukraine	56	1.7%
Sri Lanka	51	1.6%

Philippines	35	1.1%
Pakistan	32	1.0%
Indonesia	30	0.9%
Total 15 nations	3,160	96.2%
Total 45 nations	3,285	

e. Social & Behavioral Sciences

Social & Behavioral Sciences
Quartile Three

Nation	Total Doctorates	Percent of Total
China	1,141	53.4%
Indonesia	135	6.3%
Philippines	105	4.9%
Egypt	75	3.5%
Bulgaria	73	3.4%
Pakistan	71	3.3%
Jordan	67	3.1%
Romania	61	2.9%
Sri Lanka	53	2.5%
Ukraine	39	1.8%
Iran	27	1.3%
Total 11 nations	1,847	86.4%
Total 45 nations	2,137	

4. Quartile Four

a. Physical Sciences

Physical Sciences Quartile Four

Nation	Total Doctorates	Percent of Total
India	1,369	79.3%
Bangladesh	73	4.2%
Ethiopia	59	3.4%
Kenya	54	3.1%
Nigeria	38	2.2%
Ghana	26	1.5%
Total 6 nations	1,619	93.7%
Total 45 nations	1,727	

b. Life Sciences

Life Sciences Quartile Four

Nation	Total Doctorates	Percent of Total
India	2,422	75.4%
Kenya	153	4.8%
Bangladesh	80	2.5%
Ghana	77	2.4%
Ethiopia	74	2.3%
Nigeria	63	2.0%
Uganda	56	1.7%
Nepal	54	1.7%
Sudan	27	0.8%
Total 9 nations	3,006	93.6%
Total 45 nations	3,211	

c. Engineering

Engineering Quartile Four

Nation	Total Doctorates	Percent of Total
India	4,948	89.8%
Bangladesh	223	4.0%
Ghana	51	0.9%
Nigeria	49	0.9%
Nepal	33	0.6%
Ethiopia	33	0.6%
Kenya	28	0.5%
Total 7 nations	5,365	97.4%
Total 45 nations	5,509	

d. Mathematics & Computer Sciences

Mathematics & Computer Sciences Quartile Four

Nation	Total Doctorates	Percent of Total
India	1,201	89.6%
Bangladesh	29	2.2%
Total 2 nations	1,230	91.8%
Total 45 nations	1,340	

e. Social & Behavioral Sciences

Social & Behavioral Sciences
Quartile Four

Nation	Total Doctorates	Percent of Total
India	896	62.7%
Bangladesh	96	6.7%
Kenya	69	4.8%
Ghana	62	4.3%
Nepal	54	3.8%
Nigeria	46	3.2%
Ethiopia	32	2.2%
Vietnam	30	2.1%
Total 8 nations	1,285	89.9%
Total 45 nations	1,429	

Appendix D

The Population Statistic (Pstat)

1. Pstat explanation

As presented, regression testing controlled for the effects of variation in national populations. For example, students from China and India attained the most foreign S&E doctorates at American universities from 1994 to 2005, and China and India had the largest national populations. How can S&E doctoral attainment be characterized for these two nations after controlling for their large populations? In this section a national population statistic, abbreviated as "Pstat," is generated and presented for each of the five S&E fields in order to better view the relationship between population and doctoral attainment for individual nations. This population statistic (Pstat) value is a ratio, calculated by dividing the dependent variable (aggregate number of foreign S&E doctorates for a given nation) by that nation's population as follows:

Pstat value=aggregate doctoral count by nation/national population

2. Pstat Example: China

As shown in Table D.1, China has the largest aggregate S&E doctoral count in four out of the five S&E fields. How is China characterized with respect to its large S&E doctoral counts after controlling for its large population? The Pstat value will make this characterization, and is generated as follows using China and the physical sciences field as an example. In the physical sciences field, 4,950 doctorates were attained at American universities by students from China from 1994 to 2005. China's population in 1992 was 1,177,482,000. Dividing China's 4,950 doctorates by its national population of 1,177,482,000 returns the following Pstat value:

4,950 physical sciences doctorates divided by 1,177,482,000 population equals

4.2 physical sciences doctorates per one million national population,

Or: Pstat value = 4.2 (China/physical sciences)

In other words, during the time period 1994 to 2005, Chinese students attained 4.2 physical sciences doctorates at American universities per one million of China's 1992 population.

3. Comparing Pstat Values

Pstat values can be used for comparisons between nations to determine whether an individual nation is relatively under represented or over represented in its S&E doctoral count, after controlling for its population. This section compares the Pstat values for the top 20 nations by aggregate doctorate count for each of the five S&E fields (Table D.1).

Table D.1 Pstat values for the top 20 nations by aggregate doctorate count (1994-2005)

Physical Sciences		Life Sciences		Engineering		Mathematics & Computer sciences		Social & Behavioral Sciences	
Nation	Pstat	Nation	Pstat	Nation	Pstat	Nation	Pstat	Nation	Pstat
China	**4.2**	China	**5.5**	China	**7.3**	China	**1.9**	South Korea	**45.6**
South Korea	**33.6**	India	**2.8**	India	**5.7**	India	**1.4**	China	**1.0**
India	**1.6**	Taiwan	**103.4**	South Korea	**92.9**	South Korea	**21.9**	Taiwan	**44.1**
Taiwan	**45.2**	South Korea	**45.5**	Taiwan	**168.6**	Taiwan	**33.9**	India	**1.0**
Russia	**4.8**	Canada	**34.6**	Turkey	**21.9**	Romania	**15.6**	Canada	**30.1**
Canada	**18.5**	Thailand	**14.0**	Thailand	**17.2**	Russia	**2.0**	Japan	**6.5**
Germany	**6.3**	Mexico	**7.8**	Egypt	**10.0**	Turkey	**4.8**	Turkey	**7.6**
Romania	**14.2**	Brazil	**3.8**	Mexico	**5.5**	Germany	**3.4**	Mexico	**4.1**
Turkey	**5.0**	Turkey	**7.5**	Iran	**7.8**	Canada	**9.1**	Germany	**4.3**
Italy	**4.3**	Germany	**4.6**	Brazil	**2.8**	Greece	**20.7**	Italy	**5.7**
Japan	**2.0**	Japan	**2.7**	Canada	**15.3**	Brazil	**1.2**	Brazil	**2.0**
France	**4.0**	Russia	**1.6**	Greece	**38.9**	Mexico	**1.9**	Thailand	**4.8**
Mexico	**2.5**	Argentina	**6.7**	Japan	**2.8**	Italy	**2.6**	Spain	**5.2**
Greece	**19.2**	Pakistan	**1.8**	Jordan	**85.9**	Thailand	**2.3**	Argentina	**5.9**
Thailand	**3.4**	Colombia	**6.0**	Germany	**4.1**	Bulgaria	**11.6**	Israel	**40.4**
United Kingdom	**3.1**	Egypt	**3.2**	Saudi Arabia	**17.5**	Poland	**2.5**	Russia	**1.1**
Sri Lanka	**9.2**	Jordan	**48.1**	Russia	**1.8**	Japan	**0.8**	United Kingdom	**2.4**
Philippines	**2.2**	Philippines	**2.7**	Indonesia	**1.4**	Hong Kong	**16.1**	Saudi Arabia	**8.0**
Brazil	**0.9**	Greece	**17.3**	France	**4.1**	United Kingdom	**1.6**	Indonesia	**0.7**
Hong Kong	**24.0**	United Kingdom	**3.0**	Pakistan	**2.0**	Saudi Arabia	**5.3**	Greece	**12.9**

Of special note in Table D.1 are the very high Pstat values for South Korea and Taiwan across all five S&E fields. Using the physical sciences field as an example, the Pstat values are 33.6 for South Korea and 45.2 for Taiwan, while the values for China (4.2) and India (1.6) are much lower. China's Pstat value of 4.2 (again meaning that during the time period 1994 to 2005, China had 4.2 physical sciences doctorates attained at American universities per one million of its 1992 population), suggests that it was a relatively "normal" nation from 1994 to 2005 in the physical sciences, similar to those Pstat values for the United Kingdom (3.1), France (4.0), Germany (6.3), Italy (4.3) and Russia (4.8). Comparing the nations of China, United Kingdom, France, Germany, Italy and Russia in the physical sciences suggests that at first glance, controlling for national populations, variation in S&E doctoral attainment between lower income nations like China and higher income nations like the United Kingdom and Germany appears to be relatively small during the period 1994 to 2005. However, some nations have relatively high Pstat values in some S&E fields (e.g. Jordan: engineering, 85.9) equated to over representation at American universities, while some other nations have relatively low Pstat values (e.g. Brazil: physical sciences, 0.9), equated to under representation.

The hypothesis previously tested concerned whether differences in national wealth explain variation in foreign S&E doctoral attainment at American universities for each of the five S&E fields, and the use of Pstat values in Table D.1 shows the effects of controlling for population on individual nations. The population control variable in the regression testing model in effect performs a Pstat calculation for all 181 nations, and observing the Pstat values for each to the top 20 nations by doctoral count for each of the five S&E fields as shown in Table D.1 also strengthens the case for the testing of this model: there appears to be some Pstat value variation after controlling for population, but it was unclear if this variation would be explained by differences in national wealth.

4. Checking for Outlier Nations with Pstat

How can nations diverging greatly from the Pstat mean be identified and characterized?

"Observations that have large residuals associated with them are thought to reflect the presence of a fat-tailed error distribution, so a search for such "outliers" is usually the first step in addressing this potential problem" (Kennedy 2003).

In this section, the mean Pstat values for each S&E field will be presented and used to identify potential "outliers," defined as observations with large "residuals," where a residual represents the difference (positive or negative) between the actual value of the observation and its value estimated from the regression model (Wonnacott and Wonnacott 1987). In general, an observation may be considered as a potential outlier (and candidate for exclusion from testing) if its value exceeds the value of other observations by a large amount, perhaps three or four standard deviations away from the mean value of all the observations so as to "distort the slope of the regression line" (Gujarati 2003). As shown in Table D.1, the two nations to be considered as potential outliers are Taiwan and South Korea due to their very high Pstat values. Table D.2 shows how the Pstat values for Taiwan and South Korea compare with the mean Pstat values for the other 179 nations for each of the five S&E fields. The most extreme Pstat values are in engineering, with Taiwan (168.6) and South Korea (92.9) exceeding the mean Pstat value of 7.6 for 179 nations by 9.6 standard deviations and 5.1 standard deviations respectively.

Table D.2 Pstat statistics, selected nations, 1994 to 2005

	Physical Sciences	Life Sciences	Engineering	Mathematics & Computer Sciences	Social & Behavioral Sciences
179 Nation Mean	5.8	9.2	7.6	4	7.1
Standard Deviation	13.9	20	16.7	9.9	17.9
Taiwan	45.2	103.4	168.6	33.9	44.1
South Korea	33.6	45.5	92.9	21.9	45.6
China	4.2	5.5	7.3	1.9	1
India	1.6	2.8	5.7	1.4	1

Note also that the Pstat values for China are below the mean for the physical sciences, life sciences and engineering, and well below the mean for mathematics and computer sciences and social and behavioral sciences. India is well below the mean for all fields except engineering. Again, the biggest contrast is seen in the field of engineering. The Pstat value of 168.6 for Taiwan in engineering means that during the time period 1994 to 2005, Taiwan had 168.6 physical sciences doctorates attained at American universities per one million of its 1992 population while China only had 7.3. Therefore, after controlling for each nation's populations, students from Taiwan attained 23 times more engineering doctorates than their counterparts from China from 1994 to 2005.
Are Taiwan and South Korea outliers due to their high Pstat values? There is more to identifying and excluding outliers than just optimizing the fit of the regression model.

"Automatic rejection of outliers is not always a wise procedure. Sometimes the outlier is providing information that other data points cannot due to the fact that it arises from an unusual combination of circumstances which may be of vital interest and requires further investigation rather than rejection (Draper and Smith 1998)."

In this way, the cases of South Korea and Taiwan merit further investigation rather than rejection, due to possible "unusual combination or circumstances" that might have included government intervention on the part of South Korea, Taiwan and the United States in order to promote S&E doctoral attainment (Hamilton and Perry 2008).

Appendix E

S&E Doctoral Counts, 1994 to 2005, by S&E Field, by Quartile and Selected Nations

Physical Sciences Doctoral Counts

Physical Sciences	China	India	South Korea	Taiwan	Q1	Q2	Q3	Q4	Total	China Share
Year										
2005	646	143	139	56	299	275	187	62	1,807	36%
2004	584	98	144	36	315	213	170	36	1,596	37%
2003	492	104	107	39	260	245	146	23	1,416	35%
2002	432	107	113	38	265	215	132	23	1,325	33%
2001	413	83	120	53	266	240	129	28	1,332	31%
2000	471	102	94	67	260	204	108	26	1,332	35%
1999	429	89	101	64	228	220	138	22	1,291	33%
1998	400	125	92	93	244	217	104	24	1,299	31%
1997	340	142	104	107	230	202	111	27	1,263	27%
1996	359	132	138	119	241	176	87	33	1,285	28%
1995	271	116	151	134	231	141	104	24	1,172	23%
1994	113	128	172	137	237	135	91	30	1,043	11%
1994 2005	4,950	1,369	1,475	943	3,076	2,483	1,507	358	16,161	31%

Life Sciences Doctoral Counts

Life Sciences	China	India	South Korea	Taiwan	Q1	Q2	Q3	Q4	Total	China Share
2005	781	352	174	151	349	400	180	84	2,471	32%
2004	687	233	217	103	329	396	153	60	2,178	32%
2003	610	200	167	114	331	445	139	54	2,060	30%
2002	616	152	160	128	342	441	139	49	2,027	30%
2001	567	173	145	148	296	449	120	58	1,956	29%
2000	635	166	161	143	302	395	126	50	1,978	32%
1999	627	164	147	189	325	394	147	63	2,056	30%
1998	558	181	135	209	288	356	155	66	1,948	29%
1997	458	218	165	241	294	325	144	61	1,906	24%
1996	503	218	164	234	311	316	171	72	1,989	25%
1995	277	183	184	248	318	294	190	77	1,771	16%
1994	124	182	174	249	309	278	195	95	1,606	8%
1994 2005	6,443	2,422	1,993	2,157	3,794	4,489	1,989	789	24,076	27%

Engineering Doctoral Counts

Engineer.	China	India	South Korea	Taiwan	Q1	Q2	Q3	Q4	Total	China Share
2005	1,519	564	479	170	342	493	292	73	3,932	39%
2004	1,251	428	497	122	340	493	243	57	3,431	36%
2003	990	304	428	151	285	528	229	38	2,953	34%
2002	832	240	346	177	299	513	182	39	2,628	32%
2001	829	312	340	217	291	486	221	41	2,737	30%
2000	719	294	287	221	308	445	207	43	2,524	28%
1999	540	346	238	269	276	361	186	37	2,253	24%
1998	484	403	263	316	259	332	189	35	2,281	21%
1997	474	499	266	354	266	314	220	43	2,436	19%
1996	447	592	279	451	282	313	228	54	2,646	17%
1995	345	502	311	506	299	312	249	50	2,574	13%
1994	136	464	338	562	321	308	255	51	2,435	6%
1994 2005	8,566	4,948	4,072	3,516	3,568	4,898	2,701	561	32,830	26%

Mathematics and Computer Sciences Doctoral Counts

Math CS	China	India	South Korea	Taiwan	Q1	Q2	Q3	Q4	Total	China Share
2005	527	130	117	40	170	197	142	19	1,342	39%
2004	314	99	76	31	206	162	136	20	1,044	30%
2003	207	77	102	41	137	172	89	20	845	24%
2002	190	64	75	27	165	148	89	11	769	25%
2001	201	64	74	42	164	136	74	10	765	26%
2000	196	62	72	46	165	141	81	12	775	25%
1999	142	90	62	73	159	143	76	8	753	19%
1998	138	107	70	72	168	143	68	4	770	18%
1997	117	109	62	72	154	118	79	12	723	16%
1996	123	124	86	86	186	109	55	8	777	16%
1995	84	145	87	80	179	123	58	7	763	11%
1994	36	130	79	97	177	115	63	8	705	5%
1994 2005	2,275	1,201	962	707	2,030	1,707	1,010	139	10,031	23%

Social and Behavioral Sciences

Social Behavior.	China	India	South Korea	Taiwan	Q1	Q2	Q3	Q4	Total	China Share
2005	181	71	196	54	414	344	111	61	1,432	13%
2004	157	64	156	64	429	298	105	47	1,320	12%
2003	116	61	155	64	395	289	91	46	1,217	10%
2002	94	71	155	40	360	272	77	33	1,102	9%
2001	108	62	158	63	355	238	80	36	1,100	10%
2000	108	62	130	72	397	258	74	46	1,147	9%
1999	97	80	131	74	316	198	61	48	1,005	10%
1998	84	83	155	86	334	171	72	43	1,028	8%
1997	76	78	171	89	319	166	68	43	1,010	8%
1996	51	84	174	105	292	178	75	42	1,001	5%
1995	43	104	203	112	345	172	97	47	1,123	4%
1994	26	76	214	96	325	150	85	46	1,018	3%
1994 2005	1,141	896	1,998	919	4,281	2,734	996	533	13,498	8%

Appendix F

US Education-Related R&D Expenditures to Universities, By Year

Year	Physical Sciences	Life Sciences	Mathematics & Computer Sciences	Engineering	Social & Behavioral Sciences
1973	234,204	871,768	49,357	124,228	139,303
1974	242,934	1,102,832	52,848	141,205	147,465
1975	267,515	1,151,802	57,520	167,299	146,071
1976	278,106	1,247,204	57,609	172,317	177,307
1977	326,085	1,399,945	72,869	220,578	195,861
1978	366,604	1,605,247	79,489	240,875	213,794
1979	402,798	1,796,036	87,531	269,590	228,031
1980	460,974	1,984,684	94,608	323,723	227,122
1981	525,167	2,117,191	121,389	365,346	229,092
1982	559,144	2,204,998	139,651	361,508	197,006
1983	596,468	2,459,974	172,379	408,677	224,449
1984	697,754	2,800,211	181,576	474,193	223,920
1985	753,232	3,239,373	251,816	501,280	260,773
1986	751,875	3,251,816	273,903	608,969	259,527
1987	822,507	3,824,072	288,530	599,755	315,803
1988	856,885	4,029,470	305,442	673,093	334,240
1989	929,635	4,395,848	344,809	749,156	373,322
1990	1,001,514	4,531,711	414,929	712,715	412,735
1991	1,070,744	4,967,297	398,710	828,843	469,835
1992	1,150,622	5,011,126	477,677	836,083	303,639
1993	1,172,630	5,500,452	490,134	887,988	503,501
1994	1,168,476	5,743,699	540,132	954,599	515,288
1995	1,193,942	5,642,443	535,117	1,090,788	486,041
1996	1,126,675	6,018,581	650,571	1,079,626	442,093
1997	1,163,863	6,566,059	571,595	988,013	480,839
1998	1,204,162	7,005,369	624,106	992,421	486,826
1999	1,322,760	8,091,196	662,983	1,046,107	556,967
2000	1,561,163	9,357,175	792,873	1,283,447	661,170
Factor Increase 1973 to 2000	6.7	10.7	16.1	10.3	4.7

Source: (NSF 2008)

REFERENCES

REFERENCES

AAU (2006). Association of American Universities, Press Release, January 26, 2006 "AAU Announces National Defense Education Initiative."

Abramovitz, M. (1986). "Catching Up, Forging Ahead and Falling Behind," The Journal of Economic History, Vol. 46 No. 2, June 1986, pp. 385-406.

Anderson, L. (2007). Congress and the Classroom: from the Cold War to No Child Left Behind, The Pennsylvania State University, University Park, PA, 2007.

Arango, J. (2004). "Theories of International Migration," In D. Joly (Ed.), International Migration in the New Millennium. Burlington, VT: Ashgate.

Arrow, K. (1962). "The Economic Implications of Learning by Doing," The Review of Economic Studies, Volume 29, Issue 3, June 1962, p. 155.

Becker, G. (1993). Human Capital, 3rd Edition, The University of Chicago Press.

Becker, G. (1962). "Investment in Human Capital: A Theoretical Analysis," The Journal of Political Economy, Volume 70, Issue 5, Part 2: Investment in Human Beings, October.

Borjas, G. (2005). "The Labor Market Impact of High Skilled Immigration," Cambridge, MA: National Bureau of Economic Research Working Paper, Working Paper 11217.

Bracey, G. (2008). "On the Shortage of Scientists and Engineers," Phi Delta Kappan, Vol. 89, No. 7.

Burn, B. (2000). "Australia and Foreign Student Recruitment," International Higher Education, Winter 2000.

Butz, W., Bloom, G., Gross, M., Kelly, T., Kofner, A. and Rippen, H. (2003). "Is There a Shortage of Scientists and Engineers?" RAND Corporation, 2003.

Catsiapis, G. (1987). "A Model of Educational Investment Decisions," The Review of Economics and Statistics, 69 (1), 33-41.

Cheng, L. and Yang, P. (1998). "Global Interaction, Global Inequality, and Migration of the Highly Trained to the United States," International Migration Review, Vol. 32, No. 3. (Autumn, 1998, pp. 626-653.

COIMT (1970). The International Migration of High-Level Manpower: Its Impact on the Development Process, The Committee on International Migration of Talent, New York, Praeger Publishers, 1970, pp. 712-13.

DeVane, W. (1965). Higher Education in Twentieth-Century America, Cambridge, MA: Harvard University Press.

Douglas, P. (1948). "Are There Laws of Production?," The American Economic Review, Vol. 38, No. 1, Mar. 1948, pp. 1-41.

Draper, N. and Smith, H. (1998). Applied Regression Analysis, 3rd Edition, John Wiley & Sons, New York.

Drori, G., Meyer, J., Ramirez, F. and Schofer, E. (2003). Science in the Modern World Polity: Institutionalization and Globalization, Stanford: Stanford University Press.

ECS (2005). The Education Commission of the States, "Keeping America Competitive: Five Strategies To Improve Mathematics and Science Education," July 2005.

EU (2005). European Commissioner for Science and Research, "The Future of R&D as a Factor for European Competitiveness, European Policy Centre Dialogue, European Union, Brussels, 2 February 2005.

Economist (2006). "A Socratic Non-Dialogue," The Economist, July 6, 2006.

Ehrenberg, R. (1991). "Decisions to Undertake and Complete Doctoral Study and Choices of Sector of Employment." In C.T. Clotfelter, R.G. Ehrenberg, M. Getz, and J.J. Siegfried (Eds.), Economic Challenges in Higher Education. Chicago: University of Chicago Press.

Finn, M. (2005). "Stay Rates of Foreign Doctorate Recipients from U.S. Universities, 2005," Oak Ridge Institute for Science and Education, Oak Ridge, TN.

Florida, R. (2004). The Rise of the Creative Class, Basic Books: New York.

Frank, D. and Gabler, J. (2006). Reconstructing the University: Worldwide Shifts in Academia in the 20th Century, Stanford: Stanford University Press.

GAES (2002). "Discover Germany: Research and Academic Opportunities, A Joint Initiative Sponsored by the German Federal Ministry of Education and Research", German Academic Exchange Service, June 6, 2002.

Galama, T. and Hosek, J. (2008). "US Competitiveness in Science and Technology," RAND National Defense Research Institute: RAND Corporation.

Glaeser, E. (1998). "Are Cities Dying?," Journal of Economic Perspectives, 12, 1998.

Goldman, C. and Massy, W. (2001). The PhD Factory: Training and Employment of Science and Engineering Doctorates in the United States, Bolton MA: Anker Publishing.

Gujarati, D. (2003). Basic Econometrics, 4th Edition, New York: McGraw Hill.

Hamilton, R. and Perry, W. (2008). "Foreign Science and Engineering PhD Production at US Universities: During and After the Cold War," International Journal of Education Research, Vol. 3, No. 1, Winter 2008.

Hart, D. (2006). "From Brain Drain to Mutual Gain," Issues in Science and Technology, Vol. 23, Issue 1.

House Science Committee (2004). U.S. House of Representatives Committee on Science, "The Conflict Between Science and Security in Visa Policy: Status and Next Steps," February 25, 2004, Washington, D.C.

Kennedy, P. (2003). A Guide to Econometrics, 5th Edition, Cambridge: The MIT Press.

King, G., Keohane, R. and Verba, S. (1994). Designing Social Inquiry, Princeton: Princeton University Press.

Krauthammer, C. (2007). "What Sputnik Launched," The Washington Post, October 5, 2007.

Kuenzi, J., Matthews, C. and Mangan, B. (2006). "Science, Technology, Engineering, and Mathematics (STEM) Education Issues and Legislative Options," CRS Report for Congress, May 22, 2006.

Kuhn, T. (1996). The Structure of Scientific Revolutions, 3rd Edition, Chicago: University of Chicago Press.

Lerner, M. (1987). America as a Civilization, New York: Henry Holt and Company.

Lucas, R., Jr. (1988). "On the Mechanics of Economic Development," Journal of Monetary Economics, Vol. 22, pp. 1-42.

Mason Gazette (2005). "International Agreement Will Bring Chinese Students to George Mason," Mason Gazette, March 8, 2005 at: http://gazette.gmu.edu/articles/6570

Merton, R. (1973). "The Normative Structure of Science." In Merton, R. (Ed.), The Sociology of Science (pp.223-80). Chicago: Chicago University Press.

Myers, R. (1972). Education and Emigration, New York: David McKay Company, Inc.

NSF/NIH/USED/HEH/USDA/NASA (2009). NSF/NIH/USED/HEH/USDA/NASA, Survey of Earned Doctorates.

NSF (2008). National Science Foundation, Division of Science Resources Statistics (NSF/SRS), at: http://www.nsf.gov/statistics/fedfunds

Patten, M. (2002). Understanding Research Methods, 3rd Edition, Los Angeles: Pyrczak Publishing.

Piazza-Georgi, B. (2002). "The Role of Human and Social Capital in Growth: Extending our Understanding," Cambridge Journal of Economics, 2002, 26; 461-479.

Porter, M. (1998). "Clusters and the New Economics of Competition," Harvard Business Review, November-December 1998.

Romer, P. (1986). "Increasing Returns and Long-Run Growth," The Journal of Political Economy, Vol. 94, No. 5, Oct. 1986, pp. 1002-1037.

Romer, P. (1990). "Endogenous Technological Change," The Journal of Political Economy, Vol. 98, No. 5, Part 2, Oct. 1990, pp. S71-S102.

Rhee, J. and Sagaria, A. (2004). "International Students: Constructions of Imperialism in The Chronicle of Higher Education," The Review of Higher Education, Fall 2004, Vol. 28, No. 1, pp. 77-96.

Salzman, H. and Lowell, L. (2007). "Into the Eye of the Storm: Assessing the Evidence on Science and Engineering Education, Quality, and Workforce Demand," October 2007, Washington DC: The Urban Institute.

Savvides, A. and Stengos, T. (2009). Human Capital and Economic Growth, Stanford: Stanford University Press, 2009.

Saxenian, A. (2002). "Transnational Communities and the Evolution of Global Production Networks: the Cases of Taiwan, China and India," Industry and Innovation, Vol. 9, No. 3.

Schneider, A. and Ingram, L. (1997). Policy Design For Democracy, University Press of Kansas.

Solow, R. (1956). "A Contribution to the Theory of Economic Growth," The Quarterly Journal of Economics, Vol. 70, No. 1, Feb. 1956, pp. 65-94.

Stephan, P. and Levin, S. (2001). "Exceptional Contributions to US Science by the Foreign-Born and Foreign-Educated," Population Research and Policy Review, 20: 59-79.

Stiglitz, J. (1999). "Knowledge as a Public Good," in Kaul, I., Grunberg, I. and Stern, M. (Eds), Global Public Goods, UNDP/Oxford University Press, p. 321.

Time (2007). "Space Brains," Time Magazine, October 8, 2007.

US Census Bureau, (2009). http://www.census.gov/ipc.

USCC (2005). U.S.-China Economic and Security Review Commission, 2005 Annual Report at: http://www.uscc.gov/annual_report/05_annual_report.php

UN (2009). United Nations Statistics Division Statistical Database, at: http://unstats.un.org/unsd.

White House (2009). White House Press Office at: http://www.whitehouse.gov/the_press_office/Fact-Sheet-A-Historic-Commitment-To-Research-And-Education/

Wolf, C., Jr. (1993). Markets or Governments, 2nd edition, Cambridge: The MIT Press.

Wonnacott, T. and Wonnacott, R. (1987). Regression: A Second Course in Statistics, Malabar, Florida: Robert E. Krieger.

CURRICULUM VITAE

Robert V. Hamilton received his Bachelor of Arts in Political Science from the University of California Berkeley in 1982, and his Master of Arts in International Relations from the University of California San Diego in 1991. He served as a Captain in the United States Marine Corps, has lived in Japan for five years, and has worked as an international coordinator for NASA's Tropical Rainfall Measuring Mission and Global Precipitation Measurement Mission since 1993. His interest in education and emigration began as a Japanese language student in Tokyo in 1989.