International Mobility of Undergraduate and Graduate Students in Science, Technology, Engineering, and Mathematics: Push and Pull Factors

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Abstract

This study examines factors that contribute to the cross-border movement of international students in science, technology, engineering, and mathematics (STEM) fields. It analyzes characteristics of host countries (pull factors) associated with international students' arrival for education in STEM fields, as well as characteristics of home countries (push factors) related to STEM student's departure for study abroad.

The study applies trend analyses and random- and fixed-effects estimations to data from multiple national and international sources. The findings show that a) international STEM students are increasingly concentrated in countries where English is used for instruction and in countries with advanced technological capabilities; b) industrialized countries that have lower enrollments of their own students in STEM programs or aging populations tend to enroll more international STEM students; c) countries that are neither advanced nor substantially lagging in technological capability send more students abroad to pursue STEM education; and d) STEM students migrate more from countries that already have high emigration rates of highly educated citizens.

The findings have implications for higher education policies and practices. Key issues include the following: technologically marginalized countries' low STEM enrollment, which may contribute to a widening disparity in technological capability between countries; the migration of STEM students, which suggests that countries should address possible negative effects of the loss of highly skilled citizens; and the increasing use of English as the language of science, which suggests a tendency toward more English-based instruction in non-English speaking countries.

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CHAPTER ONE

INTRODUCTION

The last decade witnessed a large increase worldwide in the number of students seeking academic degrees outside their home countries. In 2010, there were over 3.7 million students in institutions of higher education outside their countries of origin, representing a 62% increase in international student enrollment since 1999 (UNESCO-UIS, 2011). This rapid expansion has become a major focus of attention among scholars and university administrators, as host countries and higher education institutions contend for larger market shares of international students. A higher share of international enrollment is an indication of a greater level of the attractiveness of a host country or institution to international students (European Communities, 2010).

Universities and colleges are motivated to recruit international students for several reasons. Commercial considerations, aimed at enhancing revenue from international students, have motivated host institutions and countries to tap into this growing higher education enterprise. Institutions have also been encouraged to recruit international students proactively for academic reasons, to bring in bright international students or to diversify the student body on campus. An emerging trend indicates that certain labor markets want to absorb international students in science, technology, engineering, and mathematics (STEM) fields after or even before graduation to expand the pool of human resources in particular disciplines (Galama & Hosek, 2009).

The cross-border mobility of students has been studied by authors from different disciplines and with a wide variety of research agendas (e.g., Agarwal & Winkler, 1985; Altbach, Kelley, & Lulat, 1985; Barnett & Wu, 1995; Chen, 2007; de Wit, 2008a; Perkins & Neumayer, in press; Rosenzweig, 2008; Shields, 2013b). Importantly, however, previous studies of international student mobility provided limited insight on the cross-border movements of students in STEM fields. The current study addresses this point. As scientific and technological knowledge and skills become critical for individuals and economies to sustain growth (UNESCO, 2005, 2010; World Bank, 2012), most societies expect universities to be accountable for supplying higher education graduates with the advanced scientific and technological knowledge and skills needed in the knowledge economy. It therefore behooves both scholars and policymakers to understand STEM enrollment in universities domestically and abroad and also to grasp the magnitude of and motivation behind student outflows. Such information is essential to meaningful discussions about brain drain (OECD, 2008b), brain gains (OECD, 2008b), and brain circulation (Agarwal, 2008; de Wit, 2008a; OECD, 2008b).

Purpose Statement

This study explores emerging patterns in the cross-border mobility of international students in science, technology, engineering, and mathematics fields (called international STEM students hereafter). Specifically, this study examines the characteristics of host countries to learn what makes certain countries able to enroll more international STEM students than other countries. Information about what salient features make a country appealing to international STEM students may be useful to university administrators and policymakers in their marketing and recruitment strategies.

As the recruitment of international students has become commercialized, much focus and discussion has been on host countries and on the market share of international students possessed by individual host countries. More attention needs to be devoted, however, to educational, scientific, and technological development in students' home countries. To this point, this present study examines five aspects of students' home countries (human capital determinants; the higher education system; science and technology intensity; economic, social, and political conditions; and bilateral links with the host country) that may contribute to student demand for tertiary-level STEM education abroad. To re-examine the demand and supply of educational programs, policymakers in students' home countries need information about what characteristics relate to the outflows of their students. Policymakers may also benefit from information about the kinds of qualifications their students acquire overseas to shape human resource strategies (for students who return after completing their academic degrees). From a host country's perspective, information about international STEM students' home countries and what stimulates international STEM students to pursue a higher education degree can help university administrators target countries that send their students and reach them through appropriate recruitment strategies.

This study also explores how bilateral links (geographic, linguistic, colonial, and social links) between host and home countries relate to the directions of international STEM student mobility.

Research Questions

This study asks, What characteristics of students' home and host countries are associated with the cross-border mobility of international students in science, technology, engineering, and mathematics (STEM) fields? It examines this overarching question through three associated research questions:

(a) What are the emerging trends in the cross-border mobility of international STEM students?

(b) How are host countries' characteristics related to their attractiveness to international STEM students (or their international STEM enrollment)?

(c) How are the characteristics of students' home countries related to student demand for tertiary-level STEM education in Australia, the UK, and the US?

Background of the Study

Within the international student population, students in science, technology, engineering, and mathematics (STEM) fields are the second largest group (after business and administration) of international students and, in 2009, accounted for approximately 29% of international students in all fields of study (UNESCO-UIS, 2011). International STEM students tend to be concentrated in a few countries of destination. In 2009, approximately 90% of these students were studying in six Organization for Economic Co-operation and Development (OECD) countries (UNESCO-UIS, 2011). The US alone hosted one-third of the international STEM students, followed by the UK (16%), France (12%), Germany (11%), Australia (10%), and Japan (5%) (UNESCO-UIS, 2011).

The Host Country and International Enrollment

The relatively high concentration of international STEM students in a small number of host countries can be explained in at least three ways. First, the OECD countries have cutting-edge research institutions and abundant expenditures on research and development (R&D), which make them appealing to STEM students from abroad. Second, the widespread use of the English language plays a role in attracting international students. As the use of English is vital for knowledge exchange worldwide (Altbach, 2006, 2011), students are increasingly interested in receiving schooling and training in English, which can be achieved through studying in English-speaking countries. The dominance of the English language in scientific research has influenced some non-English speaking countries, such as Japan, Germany, and Switzerland, to offer English-language instruction to attract students from abroad (The National Academies , 2007; OECD, 2009).

Third, the concentration of international STEM students in a small number of host countries can be explained by host countries’ or institutions’ proactive recruitment efforts. Recent reports indicate that certain countries or institutions are unable to enroll a sufficient number of national students to sustain certain science and engineering programs and therefore want to enroll students from overseas who can contribute to program viability (OECD, 2008b). In the recent decade in Europe, for instance, science and technology student numbers have increased in absolute terms but have decreased in relative terms (OECD, 2006). Europe's aging population and shortage of students, especially students in the sciences, have contributed to a strong trend whereby European institutions are actively recruiting these students from developing countries who cannot be absorbed by institutions at home (de Wit, 2008a; United Nations, 2000).

In the era of the knowledge economy, many countries are eager to succeed in the race for science and technology development. The international students who are among the most talented students in their countries have had a strong role in advancing high-technology innovation in their host countries (Douglass, 2008). In addition, these international students are generally familiar with the prevailing rules and conditions in their host countries and are able to foster international networks and collaboration in many other countries (Douglass, 2008; OECD, 2008b, 2011b). International students, particularly at the doctoral level, also contribute to the advancement of research in the host country (Hazelkorn, 2009). All these qualifications make international students a good source of highly skilled workers for whom countries compete (Douglas, 2008; OECD, 2008b).

One approach to recruiting science and engineering students is by modifying immigration policies. Accordingly, some countries, in their bids to attract highly skilled workers from around the world, have modified their immigration policies to favor international students. In Australia, for instance, the Department of Immigration relaxed immigration procedures, allowing international students in information and communication technology to apply for permanent residence, often without the necessary sponsorships from Australian employers (OECD, 2011b).

The Home Country and Student Demand for Overseas Education

Cross-border higher education is not, however, solely determined by the needs of the major hosting countries. Various factors related to students' home countries also stimulate overseas study. Above all, the search for high-quality education and better-paying jobs has been found to explain much of international human migration (Agarwal, 2008; Agarwal & Winkler, 1985; Freeman, 2006), and it is this same search that stimulates the mobility of international students (Rosenzweig, 2008, p. 80). When this kind of science and engineering education is not available in students' home countries, students often seek it overseas. In particular, high-quality science and technology education at the tertiary level requires well-equipped laboratories, modern libraries, and qualified professors and researchers. With scarce funds in developing countries, such investment in even the minimum requirements of a scientific infrastructure is difficult. Although developing countries are aware of the importance of science and technology, this awareness does not necessarily make it easy to develop an educational system that fosters science and technology. The unmet demand for science and engineering education in students' home countries may therefore have an impact on studying abroad.

While many students study abroad due to the lack of resources in their countries, there are also students pursuing overseas education despite well-developed scientific infrastructure and higher education systems in their home countries. For instance, Western European countries, where higher education enrollment ratios are the highest worldwide, have a relatively high outflow of students. The high outbound mobility rates in Western European countries are related to national policies that encourage students to study abroad to enhance personal development and employability and to foster a capacity to deal with other cultures. Similarly, a high outflow of students is also seen in Korea and Taiwan, where higher education enrollment ratios are close to 100%, suggesting that access to higher education in the home country is less a concern. Additionally, in these two countries, national students' enrollment rates in STEM programs are high, implying a great interest by their students in science and technology subjects or a great demand for science and technology labor forces in the economies, which in turn motivate students to study STEM. Students from these countries may extend their options for educational opportunities abroad, and some may choose to travel abroad to learn cutting-edge knowledge and technology from leading institutions worldwide.

Tramblay (2005) argues that "Study abroad can be part of a deliberate immigration strategy from the perspective of students" (p. 196). An increasing rate of international students staying on in their host countries for employment or residence has been found in OECD countries (e.g., Canada). When immigration is perceived as an expected benefit of studying abroad, it may thus also stimulate student mobility.

The present study responds to gaps in the literature by examining the mobility of international students in science, technology, engineering, and mathematics. It examines international STEM mobility from both host countries' and home countries' perspectives. First, the relationship between international STEM enrollment and host-country characteristics is analyzed. Second, the association between student demand for overseas STEM education and the characteristics of students' home countries is investigated. In addition to investigating factors or variables that have been studied in previous empirical research on international student mobility, the study explores and examines factors or variables neglected in previous work in order to enhance understanding of the mobility of this specific group of international students.

Overview of the Study

In Chapter Two, theories and existing empirical research on the mobility of international students are reviewed and discussed. Specifically, existing research on student demand for overseas education and the relationship between international enrollment and the characteristics of students' home countries and host countries are discussed.

Chapter Three presents the study's guiding conceptual framework. The chapter also presents the research design and methodology for the study's analyses. The data analyses utilized in the study to answer the research questions are discussed. Chapter Four presents the results of the quantitative analyses. The chapter lays out the analytical methods used to address the research questions and the results of the panel data analyses. Finally, Chapter Five provides conclusions based upon the results of the quantitative analyses. The study's findings are summarized, and their implications for theory and policy are discussed. The chapter concludes with the study's significance and presents opportunities for future research.

CHAPTER TWO

REVIEW OF LITERATURE

The purpose of this chapter is to review the theories and empirical research that provide a frame for understanding the host-country factors affecting international enrollment and the home-country factors influencing students' demand for overseas education in science, technology, engineering, and mathematics (STEM) fields. Three theoretical perspectives on international student mobility are reviewed: human capital theory, neoliberalism, and world-systems analysis. The chapter then expands to review empirical research on international student mobility.

With respect to the scope of the literature review, this chapter considers the international migration of students who move to another country for the purpose of obtaining a tertiary education degree, though certain students do migrate for other purposes, such as work and residence (OECD, 2010b; Freeman, 2006). Additionally, students who study abroad under short-term exchange programs are beyond the scope of this literature review.

Theoretical Foundations

To contextualize the relationship between host-country characteristics and international enrollment, and the relationship between home-country characteristics and student demand for overseas education, this study draws upon three theoretical lenses: human capital theory, neoliberalism, and world-systems analysis. While researchers have used different theories to explain and understand the factors that determine cross-border student mobility, human capital theory, neoliberalism, and world-systems analysis offer the most helpful lenses for understanding the factors under investigation in this study. These three perspectives offer different reasons and sometimes competing claims that underlie student mobility. Human capital theory holds that investment in education yields economic successes for individuals and for the whole economy (Becker, 1975; 2002; Mincer, 1958; Schultz, 1961). While human capital theory suggests that student demand for STEM education, local or abroad, is based on students' rational decisions (Becker, 2008), neoliberal critics argue that students' choices are influenced by market forces (Davies & Bansel, 2007). Accordingly, neoliberalism holds that increased exposure to competition results in widespread dispersal of international STEM students in "the higher education market" (Shields, 2013b). In this regard, neoliberalism differs from world-systems analysis: the latter holds that international student flows are concentrated in "powerful" countries or institutions that are capable of producing and distributing advanced knowledge and technology cross-country. The following discussion offers an elaboration of these three theoretical perspectives.

Human Capital Theory

"Human capital", as defined by Jacob Mincer in 1958, refers to an individual's traits and abilities that are economically productive (Mincer, 1958). Knowledge, skills, and traits are called human capital because humans cannot be separated from their brains, their abilities, or their health. While Mincer (1958) and Schultz (1961) found that investment in physical capital explained a relatively small proportion of economic growth in many countries, they found that investment in human capital and technology improvement fueled economic growth at a rapid speed. More recently, Becker (2002) reinforced human capital's crucial status in modern economies: "The economic successes of individuals, and also of whole economies, depend on how extensively and effectively people invest in themselves" (p. 3).

The theory of human capital holds that student demand for education, local or abroad, is based on students' rational decisions and expectations of future pecuniary and non-pecuniary returns on schooling (Agarwal & Winkler, 1985; Becker, 1975, 1990; Sjaastad, 1962). For students, non-pecuniary returns are many, such as cross-cultural awareness (Fry, 1984), global perspectives, and international networks (Funk, 2001).

In accordance with human capital theory, a favorable expected pecuniary return partly explains why students choose to pursue a higher education degree abroad. For example, the possession of an international education may positively impact a new candidate on the job market. Employers are not usually sure of the capability of job seekers, so they rely on observable characteristics (Spence, 1973). Job seekers' observable characteristics may include educational attainment, fields of study, and countries and institutions in which education and training were received. Generally, employers are often impressed that job seekers have been abroad, have been immersed in foreign cultures, and perhaps have even learned one or more foreign languages. The experiences of studying or living abroad are in many cases thought to lend to a broader, more tolerant outlook. These merits are useful in a global economy and can lead to higher salaries and promotions for those students with international education (OECD, 2010b).

Accordingly, individuals may regard studying abroad worth pursuing when the job market values overseas diplomas.

Human capital theory also underscores the possibility that potential immigration benefits consequent to studying abroad may stimulate student demand for overseas education. Due to favorable job opportunities in the US in 2005, for instance, more than two-thirds of foreign citizens who received science or engineering doctorates from U.S. universities in 2000 were living in the US (Finn, 2007).

While human capital theory asserts that students' decisions on whether and where to study abroad are based on their rational choices and implicit calculations regarding future benefits, some scholars argue that students' choices might instead be shaped or predetermined by anything other than the individual's own rational calculations. Market forces, the key feature of neoliberalism, for example, are often indicated as shaping students' choices (Davies & Bansel, 2007).

Neoliberalism

Neoliberalism emerged as an economic philosophy in the 1930s when European liberal scholars attempted to trace a so-called "Third" or "Middle Way" between the conflicting philosophies of classical liberalism and collectivist central planning (Mirowski & Plehwe,2009). Since then, neoliberalism has appeared and disappeared at different times and in varied guises, making it difficult to provide a brief overview of its history (Davies & Bansel, 2007). However, scholars currently tend to associate neoliberalism with the theories of Friedrich Hayek and Milton Friedman. Stanley Fish (2009, March) reported that neoliberalism is now commonly understood as "a pejorative way of referring to a set of economic or political policies based on a strong faith in the beneficent effects of free markets”. The beneficent effects come from the belief that as individuals, business, and institutions compete with one another, they adopt practices that are more innovative and efficient (Shields, 2013a).

Neoliberalism explains that the globalization of higher education as a phenomenon of increased global competition through initiatives such as free markets, deregulation, enhanced privatization, and an overall reduction in government control (Shields, 2013a). These initiatives encourage a global market for higher education and have had some effect. For instance, reduced visa restrictions have increased international travel and migration, and enhanced privatization of higher education has influenced universities to act like enterprises that compete with one another in the global higher education market (Shields, 2013a). The stiff competition between institutions encouraged by neoliberal policies can be seen in the widespread use of international university rankings and in the competition among universities for larger international enrollments (Hazelkorn, 2009; Shields, 2013a, 2013b).

Neoliberalism supports free markets and argues against the need for state interventions. In this, it differs from human capital theory, which is not against the belief that achieving a better life for all requires a measure of state intervention.

Ultimately, neoliberalism emphasizes competition and deregulation. It suggests that international students, clients of higher education services, are driven by market forces and thus tend to choose destination countries that have prestigious universities or countries with eased visa or immigration policies. Additionally, neoliberalism holds that the flows of international students can be influenced by proactive recruitment efforts made by institutions that are eager to enroll more international students.

World-Systems Analysis

World-systems analysis, conceptualized by Wallersterin (1974), explains “the dynamics of the capitalist world economy as a total social system” (Martinez-Vela, 2001, p. 1). This total social system is a power hierarchy: “Among the most important structures of the current world-system is a power hierarchy between core and periphery, in which powerful and wealthy ‘core’ societies dominate and exploit weak and poor peripheral societies” (Martinez-Vela, 2001, p. 4). These core societies become dominant within the social system because of their political, economic, or cultural hegemonic powers (Barnett & Wu, 1995; Chase-Dunn, 1989).

According to world-systems analysis, countries that maintain the resources and knowledge desired by others remain at the center of the world system. These centers tend to be located in large and wealthy countries, where the most prestigious institutions benefit from a full array of resources, such as funding and infrastructures. The powerful universities and academic systems tend to dominate the production and distribution of knowledge (Altbach, 2006). Consequently, these centers are capable of absorbing tremendous numbers of students from abroad. Most Western industrialized countries, including Australia, Canada, France, Germany, the UK, and the US, remain at the center of the international student exchange network (Chen & Barnett, 2000).

By contrast, countries and institutions with limited educational capacity stay at the periphery. They have fewer resources and are less capable of updating current journals and databases because of the costs involved (Altbach, 2006). They also cannot attract as many international students as their powerful counterparts. Several African countries, for example, mainly the former British and French colonies, have low capacity to provide quality higher education and have therefore remained at the periphery (Chen & Barnett, 2000). Consequently, the flows of international students are unbalanced as students generally move from less developed regions or countries to developed regions or countries.

World-systems analysis indicates that the revolution of information technology has further stabilized the central position of those, typically Western, countries advanced in high technology (Altbach, 2006; Martínez-Vela, 2001). The way Western universities communicate and store knowledge in Internet databases exemplifies how they dominate the production of advanced knowledge (Altbach, 2006). As Altbach, Reisberg, and Rumbley (2009) elaborated in the 2009 UNESCO World Conference on Higher Education, “The elite universities in the world’s wealthiest countries hold a disproportionate influence over the development of international standards for scholars, models for managing institutions, and approaches to teaching and learning” (p. 32). The use of English is becoming vital for knowledge exchange worldwide (Altbach, 2006, 2011; Lillis & Curry, 2010), so academic systems in peripheral countries must learn the ways that Western universities communicate to become involved in the knowledge system. To gain access to the Western knowledge system, students in peripheral countries may therefore choose to study in central countries or at central institutions.

These three theoretical perspectives explain international student mobility from different angles. They also suggest relevant variables for analysis. For instance, human capital theory suggests a positive relationship between household wealth and studying abroad, and a positive relationship between expected benefits of studying abroad and demand for overseas education. Neoliberalism implies that the higher education system behaves like a large enterprise in which education services are a type of commodity and students are clients. To enroll more international students, universities must compete for higher status in international university rankings, and countries must ease visa processes and immigration policies. World-systems analysis suggests that the flows of students reflect economic and political relationships between countries. This power hierarchy decides the core and the periphery in the global higher education system, and the sources of power include the possession of resources, knowledge, and technological capability.

Findings of Empirical Studies

This section examines the findings and methodological issues of existing empirical studies on the cross-border mobility of international students. The literature reviewed focuses on three major themes: (a) the relationship between host-country characteristics and international enrollment (inbound mobility), (b) the relationship between home-country characteristics and the outflows of students to pursue education overseas (outbound mobility), and (c) the bilateral links between the host country and students' home countries in relation to student mobility.

This section first considers pull factors and international STEM enrollment; it then considers push factors and student demand for overseas STEM education; it finally considers other factors related to international STEM enrollment. Certain factors apply to both the host country and the home country (e.g., the number of ranked universities in the host country, and that in the home country). To avoid repeated discussion, these shared factors are discussed in the relevant subsection.

Pull Factor and International STEM Enrollment

Previous studies found that higher quality education, immigration opportunities for international students, and global competition in science and technology influence international STEM enrollment.

Quality of higher education. Higher quality higher-education systems in the host country are appealing to international students (Mazzarol & Soutar, 2002; van Bouwel & Veugelers, 2010; Perkins & Neumayer, in press). It is, however, a challenge to compare the quality of higher education across different systems. An earlier study by Lee and Tan (1984) used input-related indicators to measure the quality of higher education: the instructor-student ratio and educational expenditure per university student. They found a positive relationship between the instructor-student ratio and the outflow of students, and they interpreted that a higher quality of education (e.g., higher instructor-student ratio) in less developed countries better qualified students for admittance to postgraduate education or even to undergraduate education in developed countries. In the recent decade, however, there has been a shift in the indicators used to measure quality of education to international university ranking.

Since ranking universities worldwide was initiated by Shanghai Jai Tong University in 2003, scholars have started to examine universities' positions in the global ranking, as a quality mark, in relation to student mobility. Countries that have internationally recognized prestigious universities tend to enroll large numbers of international students (Hazelkorn, 2009; Perkins & Neumayer, in press; van Bouwel & Veugelers, 2010).

Perkins and Neumayer (in press) investigated whether university quality drives the mobility of international students. Their indicator on quality was the number of universities in the top 200 QS World University Ranking and the number of universities in the top 500 Academic Ranking of World Universities in a host country. They concluded that having more universities ranked in the top 500 universities worldwide was a pull factor to enroll international students. This same logic (more highly ranked universities attract more international students) was thought by Perkins and Neumayer to also apply to home countries. Perkins and Neumayer hypothesized that countries with lower numbers of internationally ranked universities (or no universally ranked universities) would exhibit more outflows of students. Their results did not support this hypothesis, however.

Rather than counting the number of ranked universities in a country, Rosenzweig (2008) constructed two indicators—having any ranked universities and the average rank of universities in a country—to measure university quality both in host countries and in students' home countries. Rosenzweig found that university quality in the host country did not affect international students' choices of destination countries, holding other variables constant. However, using the same indicators to measure university quality in the home country, Rosenzweig found that a country with any ranked universities had some smaller outflows of students to the US than a country with no ranked universities, other variables being equal. Rosenzweig concluded that upgrading the quality of higher education reduces student outflows.

Immigration opportunities. According to research, certain countries have relaxed their immigration policies to attract highly qualified foreigners to sectors facing labor shortages. International students appear as a potential source of qualified workers (Tramblay, 2005). Some policy measures are therefore designed to encourage international students to come and study. Additionally, other measures aim to encourage students to stay after graduation and enter the labor market. The U.S. labor market, for example, benefits from foreign STEM talent: part of this talent enters the U.S. labor market after obtaining an advanced degree in the US and subsequently deciding to stay (Galama & Hosek, 2009). European countries also recently introduced “EU Blue Cards” (similar to green cards in the US) to encourage the immigration of highly qualified workers (EUR-Lex, 2009)

The global economic downturn in Europe and North America between 2008 and 2009 has encouraged countries to adopt more restrictive approaches to intake immigrants (OECD, 2011b). Despite the shift in immigration policies, however, international students continue to be an attractive source of labor (OECD, 2011b).

Scientific and technological capability. Countries are characterized by varied levels of technological development and have unequal access to scientific and technological knowledge (Castellacci & Archibugi, 2008). Castellacci and Archibugi (2008) argue that differences in technological capabilities explain country differences in competitiveness and diverging economic dynamics in the long run. (p. 1659). Castellacci and Archibugi (2008) examined individual countries' abilities to create and adopt advanced knowledge and new technologies, and they found the existence of three technology clusters characterized by markedly different levels of development in two aspects: (a) technological infrastructures and human skills, and (b) creation and diffusion of codified knowledge. The three technology clubs include: *Cluster 1: advanced (high infrastructures and skills, high innovation)* composed of a small set of around 20 industrialized economies*; Cluster 2: followers (medium-high infrastructures and skills, low innovation)* composed of around 70 countries. Compared to the advanced cluster, the cluster of followers shows on average a much lower innovative capability (i.e., ability to create and to imitate advanced knowledge, as measured by the number of patents, scientific articles, and Internet users). *Cluster 3: marginalized (low infrastructures and skills, low innovation)* composed of around 70 countries. Countries in this cluster are rapidly catching up in Internet and telephony but are still slow to enhance technological infrastructure, educational attainments, and enrollment in tertiary education. The innovation gap between the marginalized and the followers is widening as countries in the former cluster are unable to improve innovative capabilities in the short run.

Though Castellacci and Archibugi's (2008) study did not examine the role of international STEM students in relation to host or home countries' technological capabilities, their findings about the existence of three distinct clusters of countries in terms of technological capabilities are helpful to understand the hierarchical positions in which individual countries stand. Additionally, their study offers an argument that the educational attainments of residents and tertiary enrollment in science and engineering fields matter to an economy’s technological capabilities.

As science and technology development is highly knowledge intensive, technologically advanced countries continue to invest generously in research and development (R&D) (e.g., R&D expenditure, researchers, and science and engineering graduates) and to ensure a constant supply of highly skilled workers (Galama & Hosek, 2009). Galama and Hosek (2009) found that the US is a net recipient of foreign science and engineering talent and has benefited from hosting them. For instance, between 1980 and 2000, science and engineering employment outpaced degree production, and foreign science and engineering professionals filled the gaps. They conclude that competition for skilled workers from the global pool is likely to intensify due to significant global investment in science and technology and to demographic changes (e.g., low birth rates and aging populations).

Push Factors and Student Demand for Overseas STEM Education

Previous studies found that educational opportunities in the home country, expected benefits of studying abroad, household or national wealth, and bilateral links between the host and the home countries influence international STEM enrollment.

Educational opportunities in the home country. Earlier studies from the 1980s and early 1990s found that limited access to higher education led to the outflows of students (Lee & Tan, 1984; McMahon, 1992; Atlbach, Kelley & Lulat, 1985).Recent studies however found no statistically significant results in the relationship between access to education and demand for overseas education (Naidoo, 2007a; Shi & Jang, 2008). Two reasons explain why the previous studies do not reach consistent results regarding the relationship between access to education in the home country and student demand for overseas education. One is that different measures of access to higher education were used, and none of them are ideal indicators to compare access to higher education across countries. The other reason is that there are other factors (e.g., seeking quality education and potential immigration opportunities attached to studying abroad) that override the influence of access to education on the decision to study abroad.

In previous studies, access to higher education has been measured in very different ways depending on the model specification or the data availability. For instance, one measure used to indicate the level of demand for tertiary education in the home country is the ratio of total upper secondary enrollment to total tertiary enrollment (Lee & Tan, 1984). Lee and Tan (1984) found that excess demand for higher education in the home country was related to more students seeking education overseas. This measure is not suitable however to indicate student demand for higher education: because not all secondary graduates aspire to or are academically ready to pursue higher education, it is not reasonable to assume all secondary students demand tertiary education. A high ratio of upper secondary enrollment to tertiary enrollment does not necessarily imply unmet excess demands for higher education.

Another measure used to measure educational opportunities in the home country is the secondary enrollment ratio as a proxy of availability of higher education opportunities (McMahon, 1992). McMahon (1992) hypothesized that the availability of higher education opportunities in students’ home countries would decrease student outflows. While the results of the measurement supported McMahon's hypothesis, except in the case of low-income developing countries, it is problematic to use the secondary enrollment ratio to indicate the availability of opportunities for tertiary education. Low secondary enrollment may imply poor educational capacity at the secondary level. When there are low numbers of qualified secondary graduates to attend higher education, demand for higher education is likely to be low. The variable of secondary enrollment ratio is thus not suitable to indicate access to higher education.

Another indicator — the gross enrollment ratio for higher education — was used in two recent studies to examine international demand for U.S. higher education (Naidoo, 2007a; Shi & Jang, 2008). Naidoo (2007a) hypothesized that a high higher-enrollment rate in Asian countries would reduce demand of students from Asian countries for U.S. higher education. By examining data from 1985 to 2004, Naidoo found that the results were statistically insignificant and concluded that the availability of higher education in some Asian countries did not reduce students' demands for U.S. higher education. Asian students often attached a high value to U.S. higher education and perceived it worthy of pursuing even when students had access to higher education in their home countries. Using the same variable to examine foreign demand for U.S. graduate education, Shi and Jang (2008) found that a high rate of higher-education enrollmentin the home country was positively associated with more students studying in U.S. graduate schools, as in the case of Korea. The results of both studies indicate that the gross enrollment ratio for higher education has a positive relationship to student demand for overseas education, which is contradictory to studies conducted in the 1980s.

The divergent results on the relationship between access to higher education and demand for overseas education can be explained as a consequence of using one single indicator to measure access to higher education. Contexts and policies are very different across countries, so it is necessary to have a set of indicators to measure access to higher education, as proposed by Adelman (2009) and Kaiser and O'Heron (2005).

The other reason explaining the divergent results on the relationship between access to higher education and demand for overseas education is that despite the availability of higher education in the home country, students still seek quality education. If students' demand for quality education cannot be met in the home country, they may therefore seek alternatives overseas. For example, the population of Korea has been shrinking since 2002, and this has caused a surplus of supply in higher education as fewer students take up seats in universities (Park, 2006). However, excess demand for high quality education is still found in the Seoul (capital) region, where prestigious universities are located. As a result, many students choose to study abroad. In this case, it is clear that students demand not only access to education but also a higher quality of education.

Enrollment and graduates in science and technology fields. Scholars, government agencies, and international development organizations (e.g., Castellacci & Archibugi, 2008; NSF, 2012; OECD, 2011c; UNESCO-UIS, 2009; 2002; World Bank, 2003) assess tertiary-level enrollment or graduates in science and technology fields in individual economies, which is commonly accepted as a measure of the formation of advanced human resources in science and technology and which represents a necessary requirement for acquiring and managing advanced technological knowledge (Castellacci & Archibugi, 2008, p.1661).

Expected benefits of studying abroad. Obtaining tertiary education abroad may be a precursor to immigration, which is perceived by many students to be a potential benefit of studying abroad. Rosenzweig (2008) found that (a) host countries with higher rewards for skills (referred to as high “skill prices”) attract the most international students, controlling for the quality and quantity of higher education institutions in the host country, and (b) an increase in the supply of higher education in students’ home countries that have low skill prices, given the quality of its higher education, increases the number of students who seek graduate-level education abroad. Rosenzweig concluded that the search for jobs at better pay can explain much of the mobility of students.

Wealth. Family income and financial aid play an important role, known in the research as income effects, in student demand for overseas education (Agarwal & Winkler, 1985; Becker, 1975). National income *per capita* is commonly used as a proxy because data on international students’ family income are usually unavailable. National income *per capita* has a positive impact on the demand for overseas education (Agarwal & Winkler, 1985). That is, students from countries with higher national income *per capita* are more likely to study abroad.

Bilateral relations between the host and the home countries. Previous studies show that colonial and linguistic links influence the flow of international students (Barnett & Wu, 1995; Chen & Barnett, 2000; Cummings, 1984; Lee & Tan, 1984; McMahon, 1992). Lee and Tan (1984) found that less developed countries with English as a first or second language have, after controlling for colonial ties, a larger flow of tertiary level students to the US than those that do not. Later, Chen and Barnett (2000) adopted a network analysis to research student mobility and concluded that the impact of colonial ties has declined.

Other Factors

Several other factors are also associated with the enrollment of international STEM students: the language used for instruction (OECD, 2009; 2010a; 2011a; Altbach, Reisberg & Rumbley, 2009), demographic changes (e.g. birth rates and aging populations) (de Wit, 2008a), geographic distance (Lee & Tan, 1984), the availability of specific programs (Cummings, 1993; Lee & Tan, 1984; Agarwal & Winkler, 1985), social ties (Perkins & Neumayer, in press), social and political stability in a country (Perkins & Neumayer, in press), and the capacity of higher education systems (Rosenzweig, 2008).

An extended list of pull and push factors, compiled by de Wit (2008a), serves as a good reference for research on international student mobility. De Wit (2008a) drew on the scholarship of the 1980s, 1990s, and 2000s, such as Altbach and Lulat (1985), Cummings (1993), Davis (2003), OECD (2004), and Tremblay (2006), to design a framework to illustrate the push factors and pull factors associated with the mobility of international students. De Wit defined push factors as those that stimulated students to pursue a degree abroad, and pull factors as those that attracted students from abroad to study for a degree (de Wit, 2008a, p. 27). The 49 push and pull factors listed in de Wit’s (2008a) framework are grouped into three categories: educational factors, political/social/cultural factors, and economic factors.

Summary

A review of the empirical studies indicates a set of host-country features associated with the host country’s attractiveness to international (STEM) students or the host country’s international STEM enrollment. Additionally, the review reveals that student demand for overseas (STEM) education may be affected by or related to the characteristics of the home country. Guided by the three selected theoretical perspectives and existing empirical studies, the next chapter presents this study’s research questions, conceptual framework, data collection, and methods.

CHAPTER THREE

CONCEPTUAL FRAMEWORK AND METHODOLOGY

This study examines relationship between the characteristics of host countries, the characteristics of students' home countries, and the cross-border movement of international students in science, technology, engineering, and mathematics (STEM) fields. Human capital theory (Becker, 1975; Mincer, 1958; Schultz, 1961) provides the theoretical grounding that frames this study. According to human capital theory, when individuals perceive that potential benefits exceed the costs of education and training, they tend to invest in that education or training (Becker, 1990). However, such micro-grounding perspectives, which assume that choices such as studying abroad are influenced by individual factors (e.g., family income and the costs of studying abroad), leave some underlying questions unanswered. For example, why are certain host countries more popular among international students than their counterpart countries, and why do certain countries have large outflows of students? Therefore, in addition to studying human capital determinants, the present study examines macro-level factors to gain a better understanding of the cross-border movement of international STEM students.

This chapter begins with a discussion of this study's research questions followed by a presentation of the conceptual framework that guides the study. Next, data sources and data collection are presented. Finally, the chapter concludes with a discussion of the analytical methods employed by this study.

Research Questions

This study's overarching research question is, What characteristics of students' home and host countries are associated with the cross-border mobility of international students in science, technology, engineering, and mathematics (STEM) fields? Tertiary education builds on secondary education, providing learning activities in specialized fields of education (UNESCO, 2011). Globally, international STEM students tend to be enrolled in a small number of host countries and particularly in industrialized countries. This study thus investigates the characteristics of host countries that attract this group of students.

Students from both developing countries and from developed countries pursue STEM education abroad. To gauge the extent to which student demand for tertiary-level overseas STEM education varies by students' home countries, this study examines what characteristics of students' home countries are related to student enrollment in STEM programs in Australia, the UK, and the US, the top five host countries for international STEM students. The overarching research question addressed in this study is operationalized as three associated questions:

(a) What are the emerging trends in the cross-border mobility of international STEM students?

(b) How are host-countries' characteristics related to their attractiveness to international STEM students (or their international STEM enrollment)?

(c) How are the characteristics of students' home countries related to student demand for tertiary-level STEM education in Australia, the UK, and the US?

Conceptual Framework

A push-pull model, initially used in research on human migration (Lee, 1966), was adopted to guide this study's analytical approach. Push factors are generally associated with people's area of origin. Pull factors are generally associated with the destinations to which people move. The push-pull model is generally used to explain the factors that influence the movement of people from one area to another. In the literature, this model has been used to understand international student flows (McMahon, 1992), the decision or motivation for studying abroad (Altbach, Kelley, & Lulat, 1985), and international students' choices of destination countries (Mazzarol & Soutar, 2002). As the current study examines how STEM students' cross-border migration is associated with characteristics pertaining to students' home countries and host countries, the push-pull model for migration provided a suitable framework to meet the study's purpose.

Figures 1 and 2 illustrate this study's conceptual framework. The Pull Model proposes what host-country characteristics are associated with the host country's attractiveness to international STEM students. According to the literature on migration (Lee, 1966), "pull" factors refer to characteristics pertaining to students' destination countries. These characteristics or factors do not necessarily attract students from abroad, as the word "pull" would be literally understood. Pull factors can have a counter influence on international enrollment. For instance, visa restrictions or high tuition and fees may have a negative impact on the inflows of international students (Perkins & Neumayer, in press).

The Push Model investigates what characteristics of students' home countries are related to their students' enrollment in tertiary-level STEM programs overseas. The Push

Model explores how bilateral links between a home country and a host country relate to the direction of STEM students' movement. According to the literature on migration, "push" factors usually refer to characteristics pertaining to students' home countries (Chen, 2007; Lee, 1966), and these characteristics or factors do not necessarily drive or stimulate students to leave their home countries, as the word "push" would be literally understood. Push factors can have counter influence on students' demand for overseas education, such as prestigious higher education programs in the home country. In other words, push factors (or variables) may reduce the outflows of students.

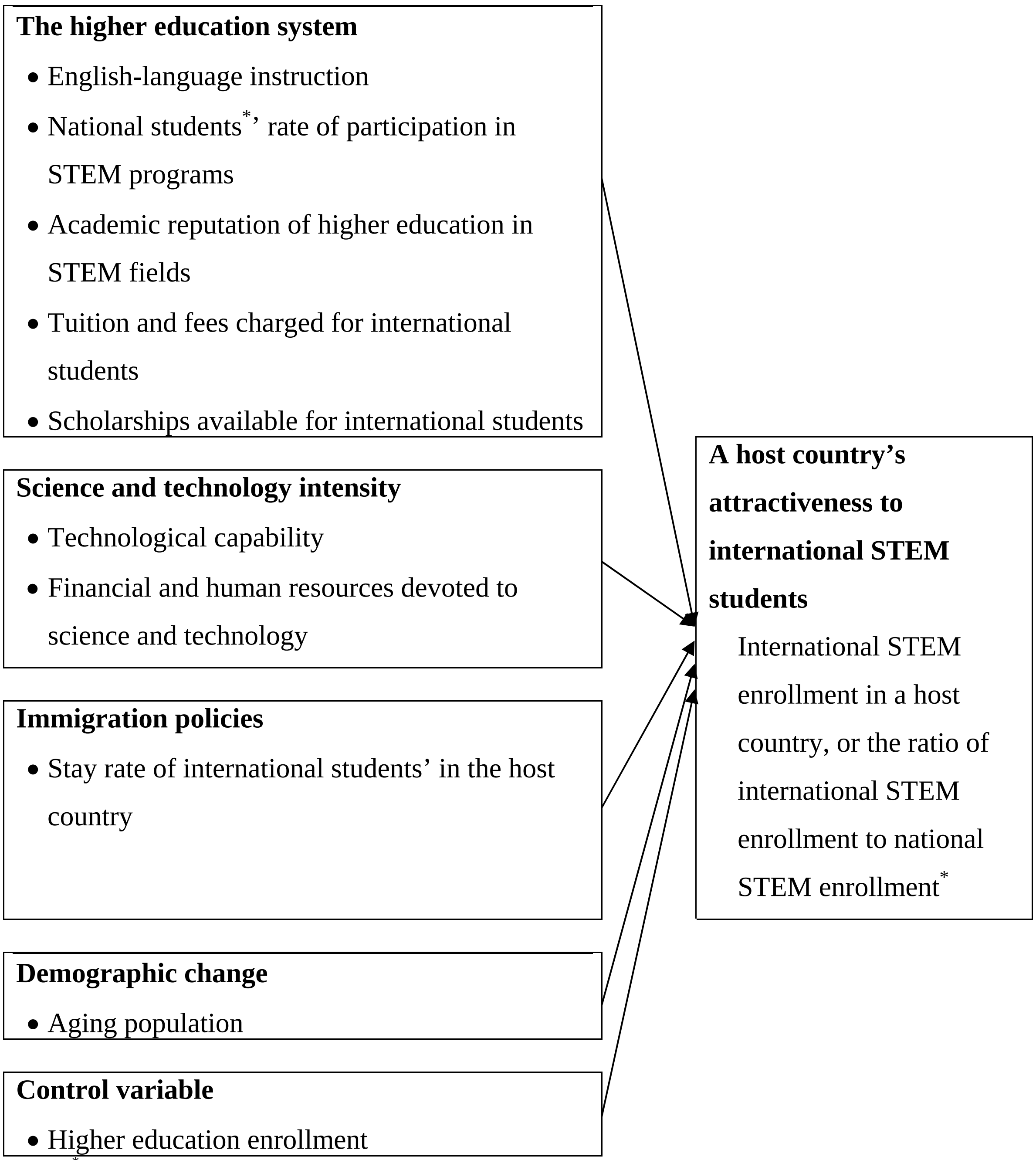
The Pull Model: A Host Country's Attractiveness to International STEM Students

The dependent variable of the Pull Model is a host country's attractiveness to international STEM students. Independent variables include four aspects of host countries, and the control variable is the total higher education enrollment in a host country.

Dependent variable. A host country's attractiveness to international STEM students is the dependent variable of the Pull Model, and it is measured by international STEM enrollment at the tertiary level or by the ratio of international STEM enrollment to national STEM enrollment at the tertiary level. A higher ratio of international enrollment is an indication of a greater level of a host country's or institution's attractiveness to international students (European Commission, 2010). Large international enrollment can be determined through the interaction of great demand by international students for education in a host country (demand) and the host country's or institution's recruitment efforts (supply).

Figure 1. Conceptual Framework: The Pull Model

The characteristics of host countries



Note. *National STEM enrollments refer to total STEM enrollments in a country excluding international STEM enrollments in that country.

Independent variables. Four aspects of the potential attractiveness of host countries to international STEM students are addressed in this study's conceptual framework: (a) the higher education system, (b) science and technology intensity, (c) immigration policies, and (d) demographic change.

The higher education system. Four variables related to a host country's higher education system are identified in this study as informing the enrollment of STEM students from abroad: (a) English-language instruction, (b) national students' rate of participation in STEM programs, (c) academic reputations, and (d) tuition and fees charged to international students and scholarships available for international students. The first three variables are empirically analyzed here; the fourth cannot be investigated due to the unavailability of data.

English-language instruction. This variable is operationalized as the use of English as the language for instruction in all, or nearly all, tertiary education programs in a country. Today, the use of English is vital for knowledge exchange worldwide (Altbach, 2006, 2011; Lillis & Curry, 2010). Most internationally circulated scientific journals, international scientific conferences, and international databases demonstrate the dominant role of the English language in the knowledge network. English is the medium of instruction in many prominent academic systems, such as Australia, Canada, the UK, and the US, all of which possess large international enrollments. The dominance of the English language has influenced some non-English speaking countries, such as Japan, Germany, and Switzerland, to offer English-language instruction to attract students from abroad (The National Academies, 2007; OECD, 2009).

National students' rate of participation in STEM programs. This variable may determine a host country's supply of STEM education to international students. The literature suggests that countries or universities are inclined to recruit international students to fill university places when they have low national STEM enrollment and a desire to have more international STEM students on campus for academic or financial reasons (de Wit, 2008a; Douglass, 2008; OECD, 2008b, 2011b). Low national STEM enrollment is possibly related to demographic change in several industrialized countries (Altbach & Lulat, 1985; de Wit, 2008a) or a decline in interest in studying physical sciences and mathematics (OECD, 2006). Both of these indicators were recently reported in OECD countries (OECD, 2006).

Academic reputation of higher education in STEM fields. High quality in the higher education system of the host country is appealing to students (Mazzarol & Soutar, 2002; van Bouwel & Veugelers, 2010). How to measure the quality of higher education across institutions or countries remains a challenge. Earlier studies used two input-related indicators to measure quality: the student-instructor ratio and the educational expenditure per university student (Lee & Tan, 1984). However, using input-related indicators to indicate quality overlooks the outputs and outcomes of higher education, which are important dimensions of quality.

A shift in the measure of the quality of higher education across national education systems has emerged since the introduction of world-wide university rankings that was initiated by Shanghai Jiao Tong University in 2003 (Liu, 2013). Countries that have internationally- recognized, prestigious universities tend to enroll large numbers of international students (Hazelkorn, 2009; Perkins & Neumayer, in press; van Bouwel &

Veugelers, 2010). Despite the fact that current world university ranking systems (e.g., Shanghai Ranking, QS World University Ranking, and Time Higher Education World University Ranking) have been criticized (e.g., for emphasizing research quality over teaching quality) (Scott, 2013; Soh, 2011, Hazelkorn, 2013), the rankings influence students' perceptions about highly prestigious universities and therefore influence students' decisions on where to study (Hazelkorn, 2009).

This study uses university rankings as a proxy for the overall academic reputation of the higher education system in a host country, but it also acknowledges both that great disparity in quality of institutions exists within a country and that a country with some internationally recognized prestigious universities may give international students the inaccurate impression that all or most universities in the country are of high quality.

Tuition and fees charged to international students and scholarships available for international students. High tuition and fees may discourage international students. According to the OECD (2012), countries that charge higher tuition fees for international students than for domestic students include Australia, Canada, New Zealand, and the US (public universities). Austria, Belgium, Netherlands, and the UK charge higher tuition fees for students from countries that do not belong to the European Union or the European Economic Area. France, Italy, and Japan charge the same tuition fees for international and domestic students. Denmark, Finland, Iceland, Norway, and Sweden charge no tuition or fees for either international or national students. Despite previous studies done in the US (Agarwal & Winkler, 1985) and the UK (Naidoo, 2007b) that suggest that high tuition and fees reduce international enrollment, universities with an entrepreneurial approach in New Zealand have successfully increased numbers of international students despite high tuition and fees (OECD, 2007a). This finding suggests that price discretion (e.g., charging different tuition and fees for different groups of students) can be compatible with goals to recruit international students.

Host countries' or institutions' financial support (scholarships, grants, assistantships) for international STEM students increases the likelihood of student enrollment. However, cross-national comparable data on financial support for international STEM students are not available for this study. Due to the absence of cross-national data on tuition and fees charged and scholarships available for international students, these two variables are not empirically examined in the study.

Science and technology intensity. The concept of "science and technology intensity" consists of two elements: (a) technological capability, and (b) financial and human resources devoted to science and technology in a country. The former reflects the *stocks* of new knowledge creation, human skills, and technological infrastructure in a country (Castellacci & Archibugi, 2008); the latter reflects the *flows* of financial and human resources devoted to science and technology.

While no empirical study has examined the relation between science and technology intensity and international STEM enrollment, international STEM students may be attracted by a country's advanced technological capabilities. To sustain or advance scientific and technological capability, host countries may seek highly skilled people from the global pool without reference to national borders. As international STEM students are a good source of such human capital, countries or institutions may make efforts to recruit them (Douglass, 2008; OECD, 2008b). This study thus examines technological capabilities, one element of science and technology intensity, in relation to international STEM enrollment.

Immigration policies. For students who use study abroad as a deliberate immigration strategy, host countries' immigration policies play a role in determining international STEM enrollment. Certain host countries relax their immigration policies to attract foreigners (workforce or students) with advanced scientific and technological knowledge and skills (EUR-Lex, 2009; OECD, 2011a; Tremblay, 2005). Specifically, perceiving international students as a good source of human resources in science and technology, certain countries (e.g., Australia, Canada, and the UK) have adopted points-based programs that make it easier for students to immigrate permanently to a host country. Students earn points for completing their education in the host country. It is possible therefore that STEM students are inclined to choose to study in countries such as Canada that reward international students in their applications for residence after they have completed their educational programs or even before completion.

This study uses the stay rate of international students in the host country as an indicator of host countries' immigration policies toward STEM workforces (OECD, 2011a) and examines its relationship with international STEM enrollment. The stay rate of international students in the host country, defined by OECD (2011b), is operationalized as the ratio of the number of international students who change from student status and residency to another status to the number of students who have not renewed their permits in a given host country.

Demographic change. In the coming decades, most industrialized countries will face aging populations and smaller proportions of prime-age workers (de Wit, 2008a;

United Nations, 2000). The aging of a population is not understood as a feature that attracts international students. Instead, this host-country variable motivates a host country to enroll more international STEM students. In particular, an aging population may lead some countries or institutions that are unable to enroll a sufficient and sustaining number of national students in science and engineering programs to enroll students from overseas who can contribute to program viability (OECD, 2008b). Europe’s aging population and shortage of students, especially in science fields, have contributed to a strong trend whereby European institutions actively recruit students from abroad (de Wit, 2008a). This study examines the relationship between a high proportion of residents aged 65 or more and international STEM enrollment. As the literature lacks an evidence-based argument about the relationship between an aging population and international enrollment, this study tests this variable empirically.

Control variable. The control variable for the Pull Model is higher education enrollment in a host country. Generally, larger higher education systems have a greater capacity to enroll larger numbers of students (both national and international).

Table 1 summarizes the expected relationship between the independent variables and the dependent variable in the Pull Model, as discussed above.

Table 1

The Pull Model: Expected Relationships between the Dependent Variable and Independent Variables

Independent variable	Expected relationship with international STEM enrollment
English-language instruction	+?[a]
National students' rate of participation in STEM programs	-
Academic reputation of higher education in STEM fields	+
Tuition and fees charged to international students	-
Scholarships available for international students	+
Technological capability	+?[b]
Financial and human resources devoted to science and technology	+
Stay rate of international students in the host country	+
Aging population	+

Note. [a]Positive if all, or nearly all, tertiary programs are offered in English. [b]Positive if a host country has advanced technological capability.

The Push Model: Student Demand for Tertiary-Level STEM Education Overseas

In the Push Model, the dependent variable is student demand for tertiary-level STEM education in Australia, the UK, and the US. The independent variables include four aspects of students' home countries and a set of bilateral links between students' home countries and host countries. The control variable is the population in a home country.

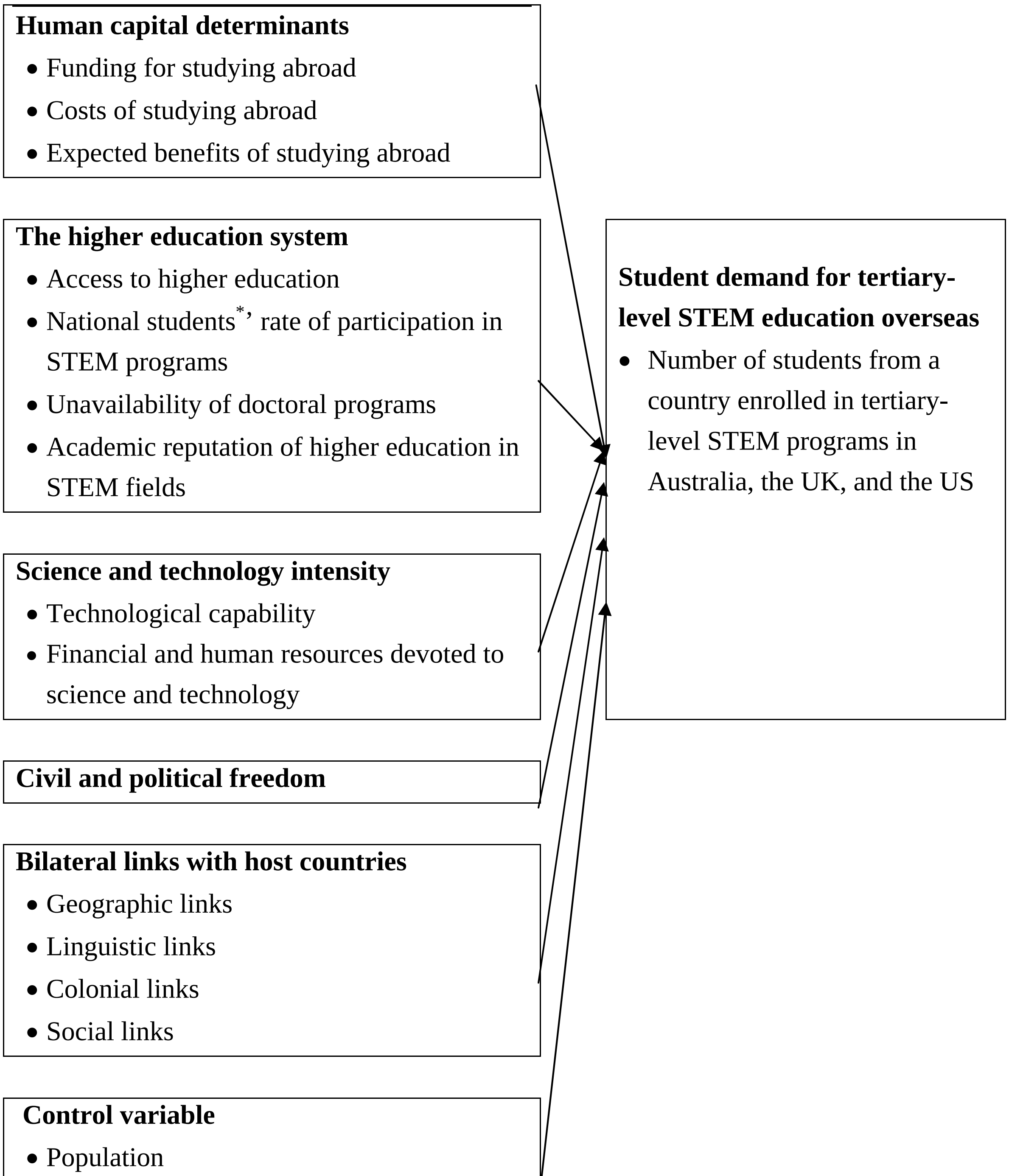
Dependent variable. The dependent variable of the Push Model is student demand for overseas STEM education. Student demand for tertiary-level overseas STEM education can be measured in two ways: (a) the number of students enrolled in tertiary-level STEM programs abroad, and (b) the ratio of outbound STEM enrollment to domestic STEM enrollment. Having more students enrolled abroad implies a greater demand for overseas education. Similarly, the higher ratio of outbound STEM enrollment to domestic STEM enrollment suggests a growing demand for overseas STEM education.

Independent variables. Five aspects of students' home countries are considered here: (a) human capital determinants, (b) the higher education system, (c) science and technology intensity, (d) civil and political freedom, and (e) bilateral links with the host country.

Human capital determinants. According to human capital theory, individuals' decisions about studying abroad and where to study are based upon a calculation that future expected returns will exceed the investment (Agarwal & Winkler, 1985; Becker, 2008; Becker & Lewis, 1993). Human capital variables include funding available for studying abroad, tuition and associated costs, and the expected benefits of studying abroad.

Figure 2. Conceptual Framework: The Push Model

The characteristics of students' home countries



Note. *National STEM enrollments refer to total STEM enrollments in a country excluding international STEM enrollments in that country.

Funding available for studying abroad. When there is more funding for studying abroad and when it is easier to obtain such funding, students are more likely to study abroad, *ceteris paribus* (Agarwal & Winkler, 1985). Funding available for studying abroad commonly includes students' family income, education loans, and scholarships. Subsidies such as scholarships, fellowships, grants, or guaranteed student loans that offset the direct costs of studying abroad also increase the likelihood of investment in schooling (Becker, 1993). Generally, most international students' funding sources come from family income (Agarwal & Winkler, 1985; OECD, 2009, 2010, 2011; Rosenzweig, 2008). The International Institute of Education in the US reported that 79% of international undergraduate students and 48% of international graduate students in the US are self- financed, by their own or their family's funding (IIE, 2010).

A lack of cross-national, comparable data on funding available for international STEM students and on family income of prospective international STEM students led this study to use *per capita* gross national income as a proxy for funding available for international STEM students.

Costs of studying abroad. The costs of studying abroad include tuition and fees, living expenses, and travel between home and host countries. Generally, higher costs of studying abroad may reduce the number of students studying abroad. Previous studies on student demand for overseas education have measured the costs of studying abroad with proxy variables, such as *per capita* gross domestic products in a destination country (Perkins & Neumayer, in press), to indicate costs of living for study abroad, and the distance between a host country and a home country to indicate travel cost (Lee & Tan, 1984).

This study excludes cost of living for study abroad because it examines more than one destination country and because time-series estimates of cost of living in different countries were not available. This study includes however a geographic variable as a proxy for travel cost, which is discussed in the subsection of bilateral links below.

This study also excludes tuition and fees for study abroad because it examines more than one destination country and reliable time-series estimates of tuition rates for students in varied disciplines and institutions across different countries were not available.

Expected benefits of studying abroad. Students indicate recognition of at least two expected benefits of study abroad: (a) after completing schooling overseas, students expect to return to their home countries and be employed with higher remuneration compared with those students who received domestic schooling, or (b) after completing schooling overseas, students expect to stay in the host country for employment or to be granted permanent residence (Agarwal & Winkler, 1985; OECD, 2010b, 2011b; Tremblay, 2005). This study examines the latter as a variable of interest, because the phenomenon of international students staying on overseas after graduation has received increased attention among scholars and policymakers.

In the case of international students who obtain jobs in countries outside their home countries, the expected benefits of schooling investments are generally estimated by a weighted average of the remuneration for persons schooled in the home country and the remuneration in a potential destination country. The weights are based on the probability of immigrating to that destination country (Rosenzweig, 2008). A needed variable is thus the immigration rate of international students from the same country of origin to a given destination country; however, this information was not available when this study was conducted.

Instead, this study used two variables: (a) the emigration rate of tertiary-educated people from a country to OECD countries, and (b) proportion of emigrants from a country to OECD countries who have attained tertiary education as an estimate of the probability of emigration. Though not all international students from the same country of origin become immigrants in their host countries, these two variables are informative about the extent to which highly education citizens in students' home countries are like to out migrate.

The higher education system. Four aspects of the higher education system in the home country were considered important to the Push Model: (a) access to higher education, (b) national students' participation in STEM education, (c) the availability of doctoral programs, and (d) the academic reputation of higher education in STEM fields. The latter three variables were examined in this study.

Access to higher education. Previous studies do not reach consensus about whether access to higher education in students' home countries affects or is associated with demand for overseas education. On the one hand, there are studies that have indicated that limited access to higher education in home countries stimulates outflows of students (Agarwal & Winkler, 1985; Lee & Tan, 1984; McMahon, 1992). On the other hand, some studies have indicated that when students attach a high value to overseas higher education, they prefer studying abroad even though they have access to higher education at home (Naidoo, 2007a; Park, 2006). There are at least two explanations for this disagreement. First, limited access causing outflows of students may apply to earlier days of student mobility when student flows were found to move mainly from the global south to the global north and from the least developed to the developed. In the current era of globalization however, in which people from different parts of the world are more connected to each other than before, young people are often encouraged to go abroad or study abroad to enhance their intercultural competence (EHEA, 2012; Funk, 2001). As a result, students from both developing and developed countries study abroad, regardless of educational opportunities in the home country, as reflected in the data disseminated by the UNESCO Institute for Statistics (UNESCO-UIS, 2009, 2013).

The other explanation for previous studies' disagreement over whether access to education is associated with demand for overseas education is the use in these studies of different measures of access to higher education and a paucity of cross-nation comparative indicators of access to higher education, as discussed in Chapter Two. Comparative indicators to measure access to higher education across countries did not exist when this study was conducted, so access to higher education was not examined.

National students' rate of participation in STEM programs. This study developed a new variable—national students' participation in STEM education—and examined the extent to which national students' participation in domestic STEM programs plays a role in student demand for overseas STEM education.

According to the UNESCO Institute for statistics (2009), there are countries, such as Iran and Malaysia, that have a relatively high level of student enrollment in science- and technology-related programs, which suggest a plentiful supply of STEM programs in these countries or students' great interest in STEM education, regardless of location. In this case, overseas STEM education may be regarded as an extension of domestic STEM education with a large number of students from these countries studying abroad.

By contrast, there are countries that have a low level of student enrollment in science and technology programs, such as Brazil and Saudi Arabia (UNESCO-UIS, 2009), because the domestic supply of STEM programs is limited or because of a low interest in STEM subjects by students. The national governments in these two countries recognize the lack of quality science and technology education domestically and provide scholarships for their students to study abroad. In this case, these countries may have a large outflow of students pursuing STEM education abroad.

Students' participation in STEM education may therefore be an indication of STEM education opportunities available in a country, and it may also reflect students' interests in STEM education. To address the lack of attention to this variable in the literature, this study examined the relationship between national students' participation in domestic STEM programs and student demand for overseas STEM education.

Unavailability of doctoral programs. Students may move abroad to pursue advanced education when specific doctoral programs are not available in their home countries (Chen, 2007). This study examined the outflow of STEM students in relation to the existence of doctoral programs in the home country.

Academic reputation of higher education in STEM fields. One motivation for students to study abroad is to receive quality higher education. There are however no objective and commonly agreed upon cross-country comparative measures of quality of education. Instead, the academic reputation of institutions, which to a certain extent is reflected in international university rankings, may be associated with students' choice to study abroad. Previous studies found that students from countries that do not have universities ranked in the top-200 world universities often move to countries that do to pursue a diploma or degree in highly ranked universities (Perkins & Neumayer, in press; van Bouwel & Veugelers, 2010). This study investigated the relationship between the presence of universities ranked as the top 500 worldwide in students' home countries and their students' demand for overseas STEM education.

Science and technology intensity. As discussed previously, science and technology intensity (or research intensity) includes two elements: (a) technological capability (Castellacci & Archibugi, 2008), and (b) financial and human resources devoted to science and technology.

The current literature lacks attention to the association between outflows of STEM students and science and technology intensity in the home country. This study addressed that lack by elaborating on three sometimes competing scenarios.

Scenario One: A high level of technological capabilities and a high level of resources devoted to science and technology are associated with low outflows of STEM students. Conversely, low technological capabilities and low resources devoted to science and technology are associated with high outflows of STEM students.

Countries with a high level of technological capabilities are capable of creating new knowledge and managing complex scientific and technological knowledge (Castellacci & Archibugi, 2008). These countries usually have a large pool of skilled human resources to perform such tasks. To sustain such capabilities, a continuous supply of higher education graduates with such skills is necessary. Accordingly, in these countries, employment opportunities in science and technology fields may motivate students to study STEM. Students in these countries may therefore be inclined to receive schooling domestically so that they may find jobs after graduation. Consequently, the outflows of STEM students are low. Countries in which Scenario One operates include the US and UK, where the number of their students enrolled in overseas STEM programs is small (about 0.5%).

On the other end of the spectrum of technological capabilities are those countries with *low* achievements in science and technology and in which technological infrastructure is fragile or missing. In these countries, there are insufficient human resources (e.g., faculty members and researchers) to provide STEM education and training in universities. Student demand for STEM education cannot therefore be met domestically. Students who can afford to study abroad may consider pursuing STEM education overseas. India is an example that falls into this scenario.

Scenario Two: A high level of technological capabilities and a high level of resources devoted to science and technology are associated with high outflows of STEM students. Conversely, low technological capabilities and low resources devoted to science and technology are associated with low outflows of STEM students.

In opposition to Scenario One, Scenario Two describes countries in which a high level of technological capabilities and a high level of resources devoted to science and technology potentially leads to high outflows of STEM students. This scenario is currently seen in European countries, where an European Union policy aims that, by 2020, at least 20% of those graduating in the European Higher Education Area should have a study or training period abroad for the purposes of personal development and employability, as well as for fostering respect for diversity and a capacity to deal with other cultures (EHEA, 2012). A typical example of a Scenario Two country is Germany (a country with advanced scientific and technological capability).

In countries with a low level of technological capabilities and a low level of resources devoted to science and technology, there are occasionally a small number of students studying in STEM programs domestically and abroad. In these countries, it is common that education systems (from primary to tertiary education) have insufficient teaching staff and facilities to provide STEM education to students. Consequently, relatively few students are prepared academically to receive university-level STEM education domestically or overseas. Many African countries fall into this group.

Scenario Three: A low level of technological capabilities and a high level of resources devoted to science and technology are associated with high outflows of STEM students.

There are currently countries with low levels of technological achievements but with national governments or private sectors committed to devoting abundant resources to enhance national technological strength. In these countries, higher education systems may undergo an expansion process to enroll students, but the speed of expansion may not be fast enough to meet student need. The unmet demand in the home country may stimulate the outflows of STEM students. China is a typical example of this group.

Using the three scenarios to guide investigation, this study examines science and technology intensity in the home country and explores their relationship to student demand for overseas STEM education.

Civil and political freedom. Civil and political freedom influences student inflows and outflows. Previous research found that individuals, including students, flee away from home countries where they lack civil and political freedom (Perkins & Neumayer, in press). In this study, the state of civil and political freedom is operationalized as “free”, “partially”, and “not free”, as assessed by the Freedom House (2012) and examined in relationship to the outflows of STEM students.

Bilateral links with the host country. Four types of bilateral links between a host country and students’ home countries are examined in this study: (a) geographic links, (b) linguistic links, (c) colonial links, and (d) social links.

Geographic links. For international students, the distance between home and host countries implies travelling costs and, sometimes, a level of cultural approximation or familiarity (e.g., knowledge of cultures or customs) between two countries. It is possible that students choose to study in countries where they will incur lower travelling costs and experience greater cultural approximation (or familiarity) than in other countries. This study examines whether STEM students tend to pursue education in another country located in the same geographic region.

Linguistic links. When international students' home countries and host countries share a common language, students incur lower costs of studying abroad as they need not spend time adapting to a new language in schooling or life. As the three destination countries in this study use English as the official language, this study examined whether the use of English as an official language in the home country has a positive relationship with student demand for STEM education in those three English-speaking countries.

Colonial links. Many students from former colonies study in former colonizing countries (Lee & Tan, 1984). A recent study found that colonial links remain significant in relation to the direction of student mobility (Perkins & Neumayer, in press).

Social links. Research found that international students tend to study in countries with an existing network of migrants from their home countries (Collins, 2008), and the marginal effects of pre-existing migrant stocks have not declined over recent years (Perkins & Neumayer, in press). This variable is operationalized as the proportion of all emigrants from the same country of origin who reside in a given destination country. This study examines the relationship between these social links and student demand for STEM education in a given destination country.

Control variables. The control variable is the total population in a home country. Generally, countries with large populations are likely to have more students available for a higher level of education, *ceteris paribus*.

Table 2 summarizes the expected relationship between the dependent variable and independent variables in the Push Model, as discussed above.

Table 2

The Push Model: Expected Relationship between the Dependent Variable and Independent Variables

Independent variable	Expected relationship with student demand for tertiary-level overseas STEM education
Funding for studying abroad	+
Costs of studying abroad	-
Expected benefits of studying abroad	+
Access to higher education	(+,-)[a]
National students' rate of participation in STEM programs	?[b]
Unavailability of doctoral programs	+
Academic reputation of higher education in STEM fields	-
Technological capability	?[b]
Financial and human resources devoted to science and technology	?[b]
Civil and political freedom	+
Geographic links	+
Linguistic links	+
Colonial links	+
Social links	+

Note. [a]Previous studies have not reached consistent results due to varied measures of access. [b]New in this study.

Data Collection

This section presents data sources, the criteria used to select cases for analyses, and the properties of the dataset compiled for this study.

Data Sources and Selection Criteria

Data used in this study were drawn from multiple sources, as summarized in Appendix A and Appendix B. Data on the number of international STEM students enrolled in individual host countries (the dependent variable of the Pull Model) were drawn from the UNESCO-UIS/OECD/Eurostat Education Data Collection (short form as UOE educational data collection), which is a joint project among the UNESCO Institute for Statistics, the Organisation for Economic Co-operation and Development (OECD), and the statistical office of the European Union. In total, 53 countries participated in this project, and these countries are either member states of the OECD or of the European Union.

Data for the dependent variable of the Push Model—in Australia, the UK, and the US, the numbers of international STEM students by country of origin—came from three national agencies: the Government Department of Education, Employment and Workplace Relations in Australia, the Higher Education Statistical Agency in the UK, and the National Science Foundation in the US.

Australia, the UK, and the US were selected as destination countries in the Push Model for two reasons: high coverage and high comparability. First, the US, the UK, and Australia ranked as the first, second, and fifth largest host countries for international STEM students worldwide, and it was estimated that these three countries alone hosted nearly half the global international STEM students in 2010, according to the UNESCO Institute for Statistics (UNESCO-UIS, 2012 July). As this study aimed to capture as many international STEM students as possible, the US, the UK, and Australia were selected.

Second, among the top six host countries worldwide (in order: the US, the UK, France, Germany, Australia, and Japan), data from Australia, the UK, and the US were relatively comparable with each other because the sources used the same operational definition for international students in their data collection. At the time this study was conducted, all three countries used “non-permanent residents” as a defining characteristic of international students, whereas France and Japan used “non-citizens.” Germany defined international students as those who received their prior qualifying education in another country before coming to Germany for tertiary education (UNESCO/OECD/Eurostat, 2012). The problem associated with using “citizenship” to define international students in quantitative work, such as this study, is that it can lead to an overestimation of the number of students who cross national borders for tertiary-level education. In France, for instance, a certain proportion of students have followed their parents or grandparents to immigrate to this country (some of these students were even born in France), but they have never obtained French citizenship. The students are counted in French national statistics as international students even though they are residents in France, have received primary and secondary educations in France, and continue tertiary education in France without studying abroad. By comparison, Australia, the UK, and the US do not count students who are residents as international students.

This study investigated students who cross borders for education (internationally mobile students), and so data on foreign students recorded by France and Japan were not suitable for this study. Germany's data were not suitable either, because German universities do not require students at the doctoral level to register. In short, this study collected data from Australia, the UK, and the US, because their data on international STEM students met the needs of this study.

The coverage of STEM fields included in this study follows the International Standard Classification of Education 1997 (ISCED 1997), which is developed by the United Nations Educational, Scientific, and Cultural Organization. According to ISCED 1997, STEM fields include life sciences, physical sciences, mathematics and statistics, computing, engineering and engineering trades, manufacturing and processing, and architecture and building.

Data on tertiary educational enrollment within each country were obtained from the UNESCO-UIS, and those data were collected through (a) the UNESCO-UIS annual survey: Questionnaire on Statistics of Tertiary Education (137 participating countries); (b) World Education Indicators Data Collection (19 participating countries); and (c) the UNESCO-UIS/OECD/Eurostat Educational Data Collection (53 participating countries). Participating countries respond to these surveys based on their administrative records. Generally, the administrative data are initially reported by schools or universities and then aggregated by successive levels of government until they comprise national figures (UNESCO-UIS, 2008).

Information about the academic reputations of higher education institutions was drawn from the Academic Ranking of World Universities (ARWU) developed by Shanghai Jiao Tong University. The ARWU adopts six research-performance-related indicators to analyze around 2,000 universities worldwide, and the top 500 are ranked (Liu, 2013). The ranking results have been published on an annual basis since 2003. Data used in this study are rankings for years 2004 and 2010.

Data on countries' technological capability were taken from the findings of Castellacci and Archibugi's (2008) empirical study. The authors' cluster analysis resulted in three distinct groups of countries in terms of a nation's technological infrastructure and skills and innovative capability: Cluster 1: *advanced* (15 countries); Cluster 2: *followers* (73 countries); Cluster 3: *marginalized* (48 countries).

Data on research and development (R&D) expenditure came from the UNESCO-UIS through its biennial survey, Questionnaire on Statistics of Science and Technology. Data on the numbers of science and technology journal articles, gross national income *per capita*, and gross domestic products *per capita* were drawn from the World Bank (2012, July).

Data on the state of civil and political freedom in a country were drawn from the *Freedom in the World* report, published by the Freedom House. The Freedom House (2012) conducts annual surveys by country or territory to evaluate the state of global freedom as experienced by individuals. Data used in this study are freedom reports for years between 2005 and 2008.

Data on emigration rates by educational attainments came from a dataset compiled by Docquier and Marfouk (2006). This work standardized the dataset on immigrants in OECD countries and developed a comprehensive dataset on international migration of people 25 years and above by educational attainment and by country of origin.

Population data were obtained from the United Nations Population Division (UNPD). The UNPD launches biennial population projections for the total population and population by age in individual countries.

With respect to data on bilateral links, data on colonial links and linguistic links came from the Centre d'Etudes Prospectives et d'Informations Internationales (Institute for Research on the International Economy) (CEPII, 2012, July). Data on social links were drawn from the Global Migrant Origin Database Version 4, which relies on the data source of the Database on Immigrants in OECD and non-OECD countries (a joint database of OECD and the World Bank) and which is maintained by the University of Sussex.

The Properties and Quality of the Dataset

Before selecting suitable statistical models to answer this study's research questions, the properties of the dataset compiled for this study were assessed. With respect to the Pull Model (host countries' attractiveness to international STEM students), data were initially drawn from the 35 OECD member states for the seven–year time span, 2004 to 2010. Among these 35 countries, 12 countries did not have data on international STEM enrollment (the dependent variable), so they were removed from the analysis. As for independent variables, missing data points accounted for 0.7% of the data on the seven independent variables in the Pull Model (8 out of 1,127), and these missing data points were imputed by linear interpolation, using the average of two available data points in adjacent years or the value adjusted with an average growth rate. Eventually, a balanced dataset containing data for 23 countries measured over seven years was obtained and analyzed.

With respect to the Push Model (student demand for overseas STEM education), data were initially drawn from 200 countries worldwide. Data for the dependent variables (the numbers of international STEM students, by country of origin, who studied in Australia, the UK, and the US) were relatively complete. Missing data points for independent variables was however a serious issue. To avoid overuse of imputation and retain sufficient cases to be examined in this study, two selection criteria were used for analysis: (a) values for the dependent variable were present; and (b) data on a country's tertiary enrollment and tertiary enrollment in STEM fields were present. As a result, imputation by adopting linear interpolation for missing data points accounted for 2.0 % among 16 independent variables (160 out of 7,872). Eventually, a balanced dataset containing data for 124 countries measured over four years between 2006 and 2009 was obtained and analyzed (see Appendix A). In order to avoid losing more cases for analysis, dependent variables that had a value of 0 were replaced with value one (because the log of 0 is undefined). In all, 0.9% of total cases were assigned a value of one.

Methods

To answer the three research questions in this study, two separate analyses were conducted. The first analysis (Pull Model) examines where STEM students study abroad and the host countries more likely to enroll a large number of international STEM students. The second analysis (Push Model) investigates the countries more likely to have a large outflow of students pursuing STEM education in Australia, the UK, or the US. This section discusses the selected statistical models for the study, followed by measures of variables.

Fixed Effects and Random Effects Models

This study used regression models for panel data (or cross-sectional, time-series data) to answer the questions proposed in this study, because these longitudinal data have more variability and allow for more exploration of issues than do cross-sectional or time-series data alone (Kennedy, 2008, p. 282). Additionally and importantly, panel data modeling controls to a certain extent for unobserved country-level heterogeneity (e.g., contextual and historical factors) that does not rapidly change within countries over the time period studied.

In order to select a better-fitting statistical model for panel data analysis, Park's (2011) guidelines on panel data modeling process were followed. The pooled ordinary least squared (pooled OLS) estimation (usually suggested as the initial step of panel data modeling) was considered unsuitable for the panel data in the Pull Model because observed and unobserved heterogeneity existed between countries with respect to their attractiveness to international STEM students. Each country had its own distinctive attractiveness to international students from different parts of the world, such as cultural aspects (heterogeneity between countries), which is not captured in pooled OLS statistical models. Pooled OLS was thus not considered in the study of the Pull Model. Similarly, pooled OLS was not considered in the study of the Push Model because observed and unobserved heterogeneity exists between countries with respect to their student demand for STEM education in Australia, the UK, and the US.

In the analysis done for the Push Model, fixed-effect estimation was not performed for two reasons. First, random-effect estimations were more suitable for this analysis than fixed effects estimations because the individual dimension N (124 countries) is large relative to the time dimension T (2006 - 2009, four years), and thus, group effects can be viewed as random (Park, 2011). Second, random effects models offer the technical advantage that time-invariant independent variables (e.g., technological capability: advanced, followers, and marginalized) can be examined, while they are annulled in the least-squared dummy variables procedure (Kunst, 2009; Park, 2011).

Random effects models assume that the individual country's heterogeneity was captured in the disturbance term and that the individual (group) effect is not correlated with any independent variables (Park, 2011), whereas fixed effects models examine individual differences in intercepts and assume the same slopes and constant variance across individual countries.

Equation (3.1) is the functional form of one-way random group effects models:

(3.1) $y_{it} = \alpha + \beta_1 x_{1it} + ... + \beta_k x_{kit} + (u_i + v_{it})$, where u_i ~IID $(0, \sigma_u^2)$, and v_{it} ~IID $(0, \sigma_v^2)$

And equation (3.2) is the functional form of one-way fixed group effects models:

(3.2) $y_{it} = (\alpha + u_i) + \beta_1 x_{1it} + ... + \beta_k x_{kit} + v_{it}$, where v_{it} ~IID $(0, \sigma_v^2)$, and

where i denotes the i^{th} country; t represents the t^{th} year; α is the intercept of the model; β_k is the coefficient associated with the independent variable x_k; u_i is the intercept of the i^{th} country, and v_{it} denotes the error terms. It is noted that *u* is a fixed or random effect specific to an individual country that is not included in the regression, and errors are independently identically distributed, v_{it} ~IID $(0, \sigma_v^2)$.

Next, in order to determine whether any significant random effect existed, the Breusch-Pagan Lagrange multiplier (LM) test was performed. The null hypothesis is that individual-specific error variance components are zero. If the null hypothesis of the LM test is rejected, it suggests that random effects exist.

(3.3) $$H_0 : \sigma_u^2 = 0.$$

To examine whether any significant fixed group effects exist, an F-test should be performed. The null hypothesis of the F-test is that all country dummy parameters except for one are zero. If the null hypothesis of the F-test is rejected, it suggests that fixed effects exist.

(3.4) $$H_0 : \mu_1 = ... = \mu_{n-1} = 0$$

When both null hypotheses of the Lagrange multiplier (LM) test and the F-test are rejected, the Hausman test needs to be performed in order to determine between random effects models and fixed effects models, which ones are more suitable.

During the modeling process in the study, in some cases, the tests suggested the appropriateness of random effects models and, in others, it led to the use of fixed effects models. The results of the modeling process are described more completely in Chapter Four.

This study used the STATA Version 11.0 statistical package to perform regression models for panel data.

The Wooldridge test was performed to detect the presence of autocorrelation in panel data. Test results indicate that autocorrelations exist in the dataset analyzed. The STATA correction for autocorrelation, based on the Wooldridge test was used.

Measures

The measures of the variables and data sources used in this study are summarized in Appendix B and Appendix C. The following describes the characteristics of all the variables.

International STEM enrollments: This variable is the number of international students enrolled in tertiary-level programs in science, technology, engineering, and mathematics fields (STEM) in a host country in a year. International students analyzed in this study include diploma- or degree-seeking students and excluded students in exchange programs. The variable is continuous and is transformed into a natural log value because of highly skewed distributions of absolute numbers.

The ratio of international STEM enrollment to national STEM enrollment: This variable is the ratio of international students enrolled in tertiary-level STEM programs in a host country to the number of national students enrolled in tertiary-level STEM programs in that country in a year. The variable is continuous and is transformed into a natural log value because of highly skewed distributions of percentages.

English as the language of instruction: This variable is a dichotomous variable with a value 1 when English is the language for instruction in all, or nearly all, tertiary education programs in a country; the variable is otherwise coded as 0.

National students' participation rate in STEM programs: This variable is measured by the number of national students enrolled in domestic tertiary-level STEM programs in a year and is expressed as a percentage of the 5-year age group starting from the age that students typically graduate from secondary school. The variable is continuous and expressed as a percentage.

The academic reputation of higher education: This variable denotes the percentage, which is the number of universities in a country (out of every 100 universities in a host country) ranked in the top 500 universities in the Academic Rankings of World Universities divided by total number of universities in the country in a year. The variable is continuous and expressed as a percentage.

Technological capability: Based on a country's technological capability (Castellacci & Archibug, 2008), three dichotomous variables were created. *Technological capability: Advanced* is a dichotomous variable with a value 1 for a country with high or advanced technological capability (featuring high infrastructure and skills and high innovation); the variable is otherwise coded as 0. *Technological capability: Followers* is a dichotomous variable with a value 1 for a country with mid-status technological capability (featuring medium-high infrastructures and skills and low innovation); the variable is otherwise coded as 0. *Technological capability: Marginalized* is a dichotomous variable with a value 1 for a country with low or marginalized technological capability (featuring low infrastructures and skills and low innovation); the variable is otherwise coded as 0.

According to Castellacci and Archibug (2008), technological capability represents a structural factor, and substantial changes in the relative standing of nations in terms of technological capabilities do not occur in a short time span. This variable is therefore time-invariant during the time span studied in this study.

Gross expenditure on research and experimental development (R&D): This variable denotes total domestic intramural expenditure on R&D in a year, expressed as a percentage of the gross domestic products (GDP) (UNESCO-UIS, 2013). For cross-national comparisons, US dollars are used. The variable is continuous and expressed as a percentage.

Percentage of population aged 65 or above: This variable denotes the population aged 65 years and above, expressed as a percentage of the total population in a country. Population is based on the *de facto* definition of population, which counts all residents regardless of legal status or citizenship, except for refugees not permanently settled in the country of asylum (World Bank, 2013). The variable is continuous and expressed as a percentage.

Stay rate of international students: The variable is expressed as the ratio of the number of international students who change from student-related status and residency to other statuses (e.g., work visas, permanent residency, citizenship) to the number of students who have not renewed their permits in a host country (OECD, 2011b). The variable is continuous and expressed as a percentage.

Tertiary education enrollment: This variable denotes the total number of students enrolled in tertiary education institutions in a country. The variable is continuous and was transformed into a natural log value because of highly skewed distributions of absolute numbers.

Student demand for tertiary-level STEM education abroad: This variable is operationalized as the number of students from a country who are enrolled in tertiary-level STEM programs abroad. In this study, destination countries analyzed in the Push Model include Australia, the UK, and the US. Ideally, student demand measures the number of students enrolled in tertiary-level STEM programs abroad as a percentage of the number of students enrolled in tertiary-level STEM programs domestically (the ratio of outbound STEM enrollment to domestic STEM enrollment); however, the denominator of the ratio is correlated with an independent variable, and so this study uses number (instead of ratio) as the dependent variable. The variable is continuous and was transformed into a natural log value because of highly skewed distributions of absolute numbers.

Funding for studying abroad: Gross national income per capita, purchasing power parity (GNI per capita PPP) was used as a proxy for funding for studying abroad. The variable is continuous.

Emigration rate of tertiary-educated people from a country to OECD countries: This variable shows the stock of emigrants who are aged 25 years and older, who have at least one year of tertiary education and who are residing in a member state of the OECD other than that in which they were born, as a percentage of the population aged 25 years and older with tertiary education in the home country (Docquier & Marfouk, 2006; World Bank, 2013). Most OECD members are high-income economies and are regarded as developed countries, and so immigration to OECD countries can be perceived by people from less developed countries as opportunities for getting better-paid jobs and life. The variable is continuous and expressed as a percentage.

Proportion of emigrants from a country to OECD countries who have attained tertiary education: This variable is the percentage of emigrants from the same country of origin who reside in OECD countries and who have attained tertiary education divided by the total number of emigrants from the same country of origin who reside in OECD countries. The variable is continuous and expressed as a percentage.

Unavailability of doctoral programs: This variable is a dichotomous variable with a value 1 when doctoral programs are not available in a country; the variable is otherwise coded as 0.

Scientific and technological journal articles per 100,000 inhabitants: This variable denotes the number of scientific and technical journal articles published per 100,000 inhabitants in a country. The variable is continuous.

Civil and political freedom: Based on the assessment of political rights and civil liberties in a country in the preceding year, which was rated by the Freedom House (2012), three dichotomous variables were created. *Civil and political freedom: Free* is a dichotomous variable with a value 1 for a country classified as “free” by the Freedom House; the variable is otherwise coded as 0. *Civil and political freedom: Partially free* is a dichotomous variable with a value 1 for a country classified as “partially free” by the

Freedom House; the variable is otherwise coded as 0. *Civil and political freedom: Not free* is a dichotomous variable with a value 1 for a country classified as “not free” by the Freedom House; the variable is otherwise coded as 0.

Geographic links: This variable is a dichotomous variable with a value 1 for a country located in the same geographic region as a host country; the variable is otherwise coded as 0.

Linguistic links: Linguistic links measured whether a home country and a host country share a common official language. Since the three host countries analyzed in the study—the US, the UK, and Australia—use English as an official language, the variable of linguistic links is a dichotomous variable with a value 1 for a home country in which English is an official language; the variable is otherwise coded as 0.*Colonial links:* This variable is a dichotomous variable with a value 1 for a country that has ever been a colony of a given host country; the variable is otherwise coded as 0. *Social links:* This variable measures the number of individuals born outside their current country of residence, from the same country of origin, and residing in a given destination country (Australia, the UK, or the US), divided by the total number of emigrants from the same country of origin in all destination countries. The variable is continuous and expressed as a percentage.

Population: The variable is a country’s total population. The variable is continuous and is transformed into a natural log value because of highly skewed distributions of absolute numbers.

CHAPTER FOUR

RESULTS

This chapter presents descriptive and analytical results related to this study's research questions: (a) What are the emerging trends in the cross-border mobility of international STEM students? (b) How are host-countries' characteristics related to their attractiveness to international STEM students (or their international STEM enrollment)? (c) How are the characteristics of students' home countries related to student demand for tertiary-level STEM education in Australia, the UK, and the US? First, an overview of the study's analytical approaches is presented. Next, panel data analyses are discussed and presented.

Overview

In order to answer the research questions in the study, regression models for panel data were utilized to conduct two separate analyses of international STEM enrollment. The first analysis examines where STEM students study abroad and the host countries more likely to enroll a large number of international STEM students. The second analysis investigates the countries more likely to have a large outflow of students pursuing STEM education in Australia, the UK, or the US.

Analysis I: Pull Model

The Pull Model examines how four aspects of host countries—higher education capacity and academic reputation, national technological capability, economic factors, and demographic factors—are associated with host countries' attractiveness to international STEM students.

To examine host-country characteristics in relation to international STEM enrollment, several analyses were conducted. Following the assessment of the properties and the quality of the panel data (as described in Chapter Three), trend analyses and descriptive analyses were performed to identify emerging trends in international mobility of STEM students and to present a profile of the countries analyzed in the Pull Model. Correlations between variables were tested to determine whether multicollinearity existed and required adjustments to variable groupings and planned analyses. Finally, random-effect and fixed-effect estimations were performed and presented, as they were found to be more appropriate statistical models than pooled ordinary least squares regression models.

Trend Analyses

Trend analyses were conducted to examine the emerging trends in international STEM students' choice of study-abroad destinations. Figure 3 shows the number of international STEM students who were enrolled in 23 OECD countries in 2010. The top five host countries were the US, UK, France, Germany, and Australia; the bottom five host countries were Norway, Poland, the Netherlands, Hungary, and Denmark. The US alone hosted approximately one-third of the international STEM students in these 23 countries.

The order of rankings changes when national students enrolled in domestic tertiary STEM programs (called "national STEM students") are taken into account. Figure 4 displays the ratio of international STEM enrollment to national STEM enrollment. In the US, the ratio was 8% (eight international STEM students to 100 national STEM students), which was much lower than that for Australia (34%), whose

Figure 3. Number of International STEM Students by Host Country, 2010

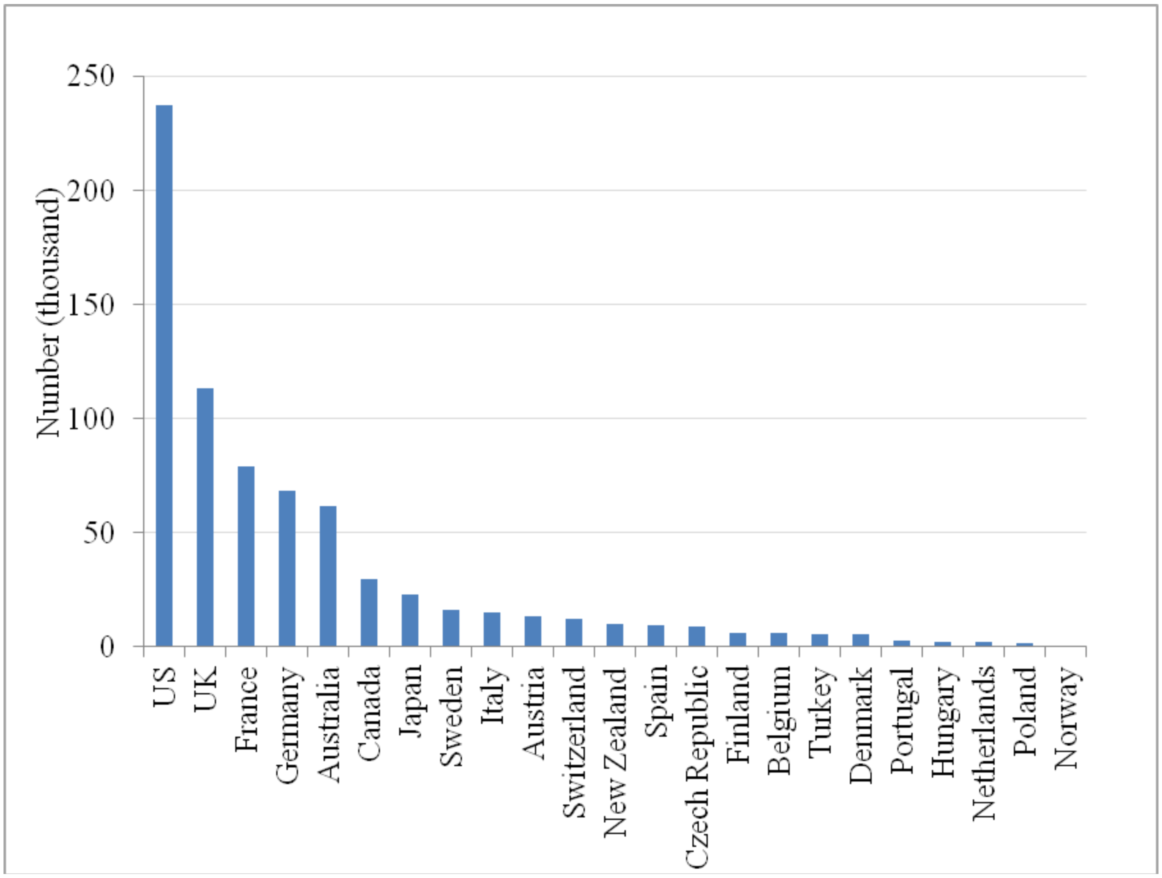
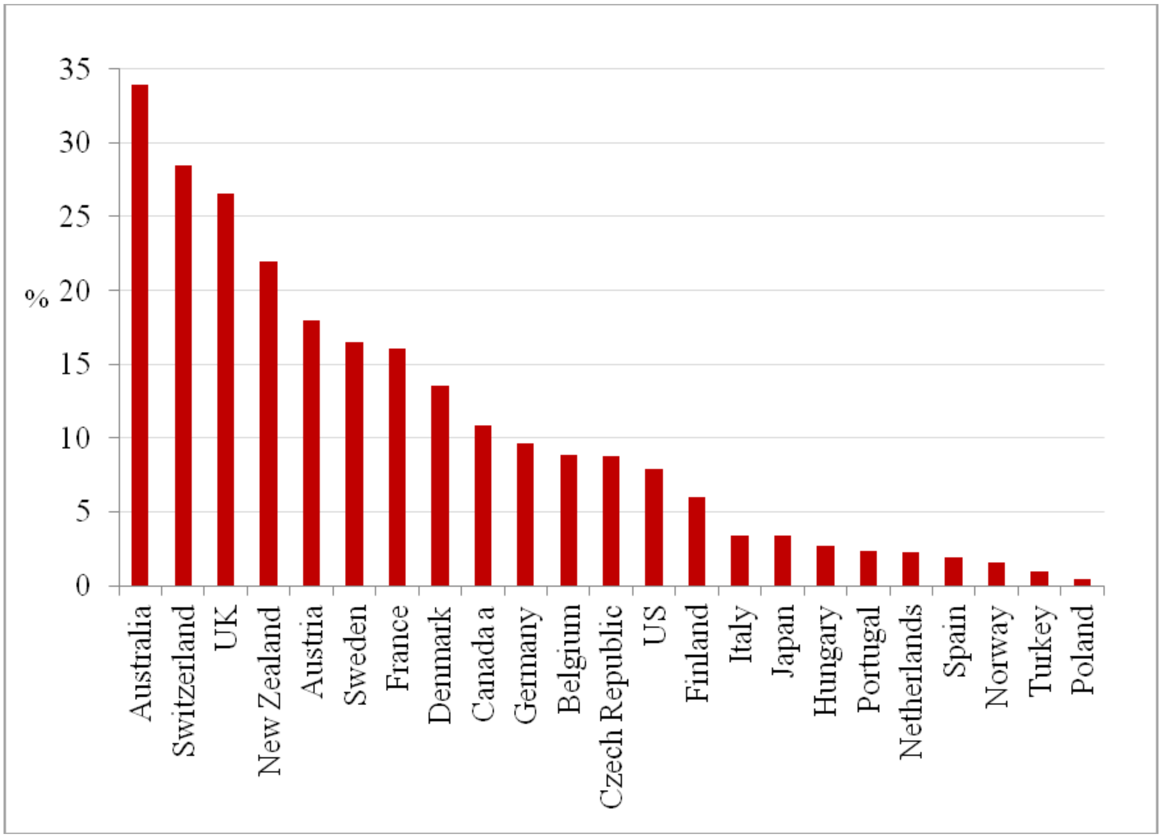


Figure 4. Ratio of International STEM Enrollment to National STEM Enrollment in 23 OECD Countries, 2010



ratio is the highest among these 23 OECD countries.

Figure 5 displays the mean number of international STEM students hosted in the 23 OECD countries. The number also includes students from OECD countries who are international students in OECD countries other than their own countries. The plot shows an upward slope over time, meaning that the number of international STEM students increased. The plot suggests that a linear model may be appropriate.

Taking into account the number of national students enrolled in tertiary-level STEM programs, the mean ratio of international STEM students to national STEM students also increased steadily over time, from 8% (eight international STEM students to 100 national STEM students) in 2004 to approximately 11% in 2010 (Figure 6). This increase in the mean ratio suggests that international STEM students account for an increasing share of total tertiary-level STEM enrollment in the 23 host countries examined in this study's Pull Model. The increase also suggests that the growth of the international STEM student population is faster than that of national STEM students.

Figure 7 and Figure 8, which show plots for English-speaking countries and their counterpart countries, illustrate the influence of English language instruction in attracting international STEM students. These plots suggest that countries where all or most educational programs are offered in English (usually English-speaking countries) host many more students than do their counterparts (i.e., non-English speaking countries). Although both slopes increase, the slope for English-speaking countries increases at a greater rate than the slope of their counterparts.

Figure 5. Mean Number of International STEM Students in a Host Country, 2004-2010

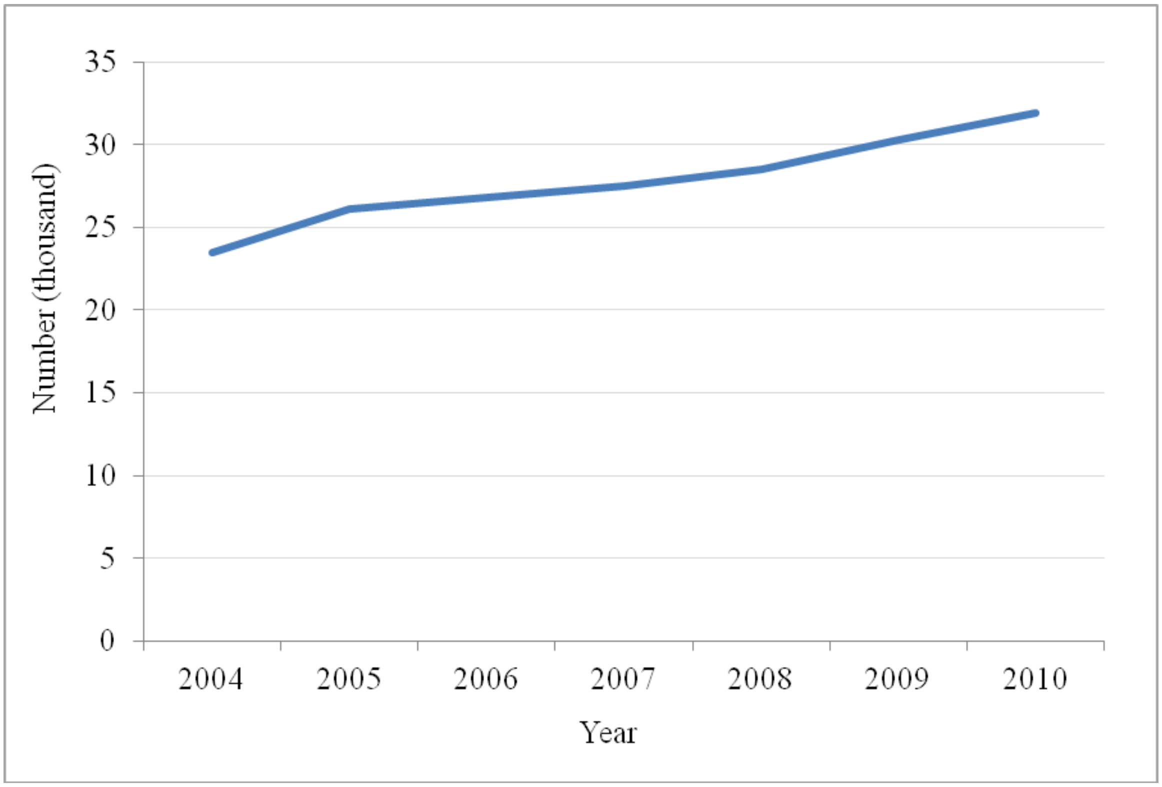
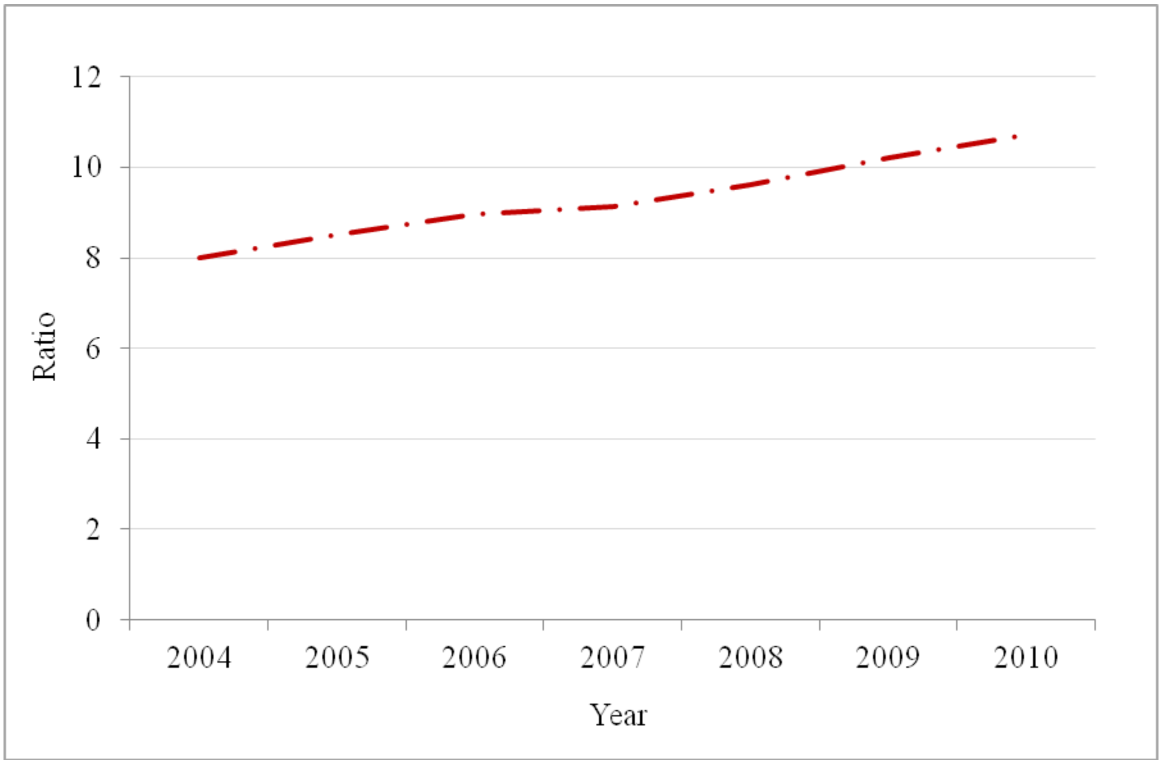


Figure 6. Mean Ratio of International STEM Enrollment to National STEM Enrollment in a Host Country, 2004-2010



Similarly, in order to evaluate a country's technological capability in relation in international STEM enrollment, international STEM enrollments in technology-advanced countries were compared to international STEM enrollments in technology-follower countries. Figure 9 and Figure 10 show the plotted results. The figures suggest that countries with advanced technological capabilities enroll more students than do their counterparts.

In summary, the results of the trend analyses suggest several key points. First, the US, the leading host country, hosted one-third of the international STEM students enrolled in higher education institutions in 23 OECD countries. Taking national STEM enrollment into account, however, Australia has the highest ratio (34%) of international STEM enrollment to national STEM enrollment. The ratio is 8:100 for the US. Second, international STEM enrollment in OECD countries has increased, both in absolute numbers and in ratios. The mean number of international STEM students hosted by an OECD country increased by a factor of 1.4 between 2004 and 2010. The mean ratio of international STEM students to national STEM enrollment increased from 8% to 12%, suggesting that the growth of the international STEM student population is faster than that of national STEM students. Third, as more STEM students study abroad, these students appear increasingly concentrated in English-speaking countries. Fourth, countries with advanced technological capability appear to be more attractive to international STEM students.

Figure 7. Number of International STEM Students in English-Speaking Versus Non-English Speaking Countries, 2004-2010

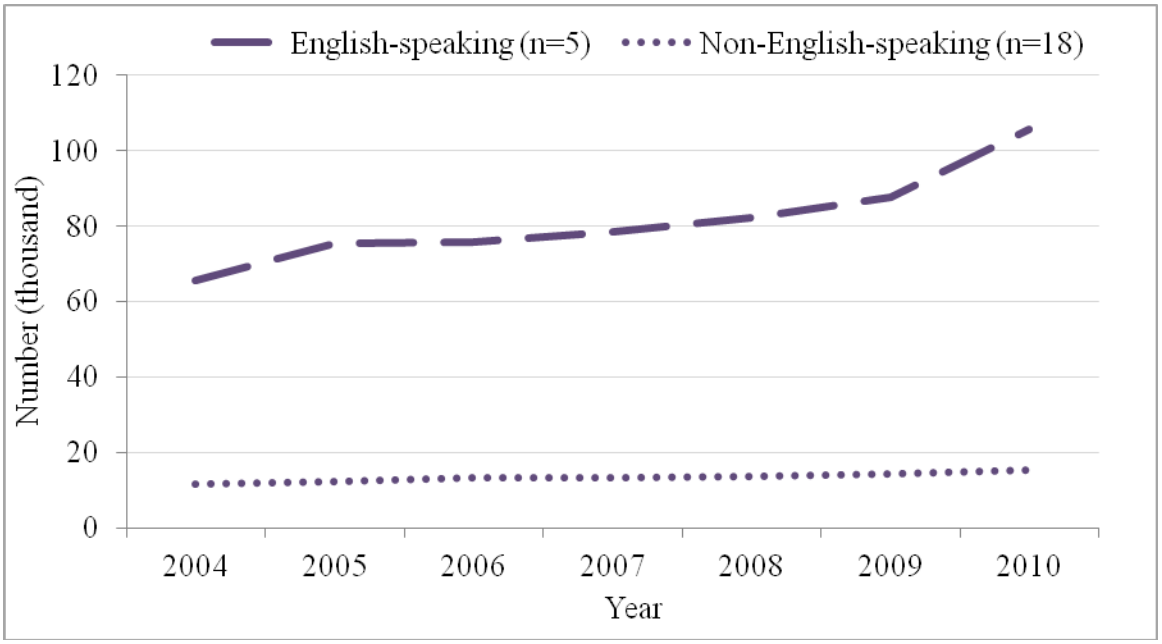


Figure 8. Mean Ratio of International STEM Enrollment to National STEM Enrollment in Host Country: English-Speaking Versus Non-English-Speaking Countries, 2004-2010

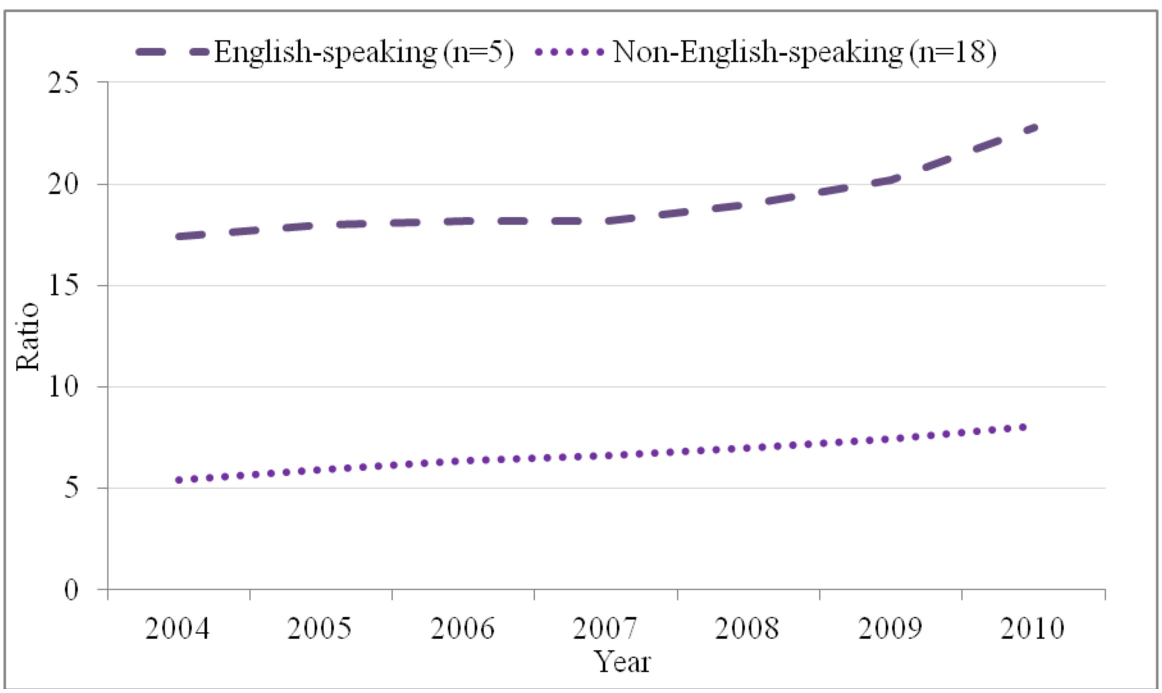


Figure 9. Number of International STEM Students by Country of Technological Capability: Advanced Versus Followers, 2004-2010

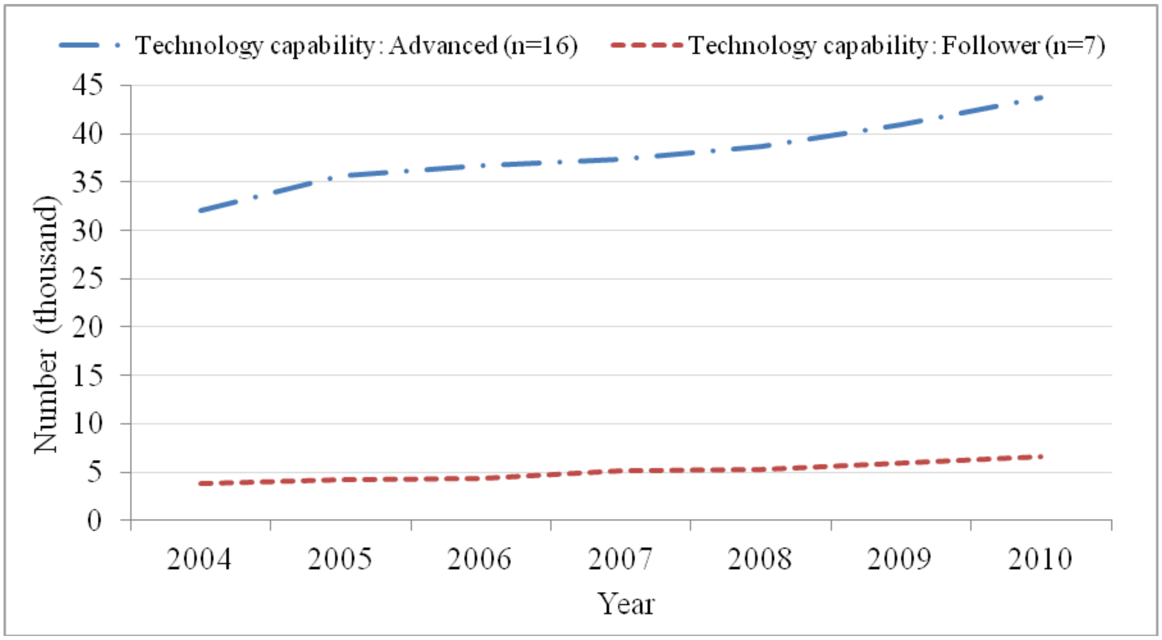
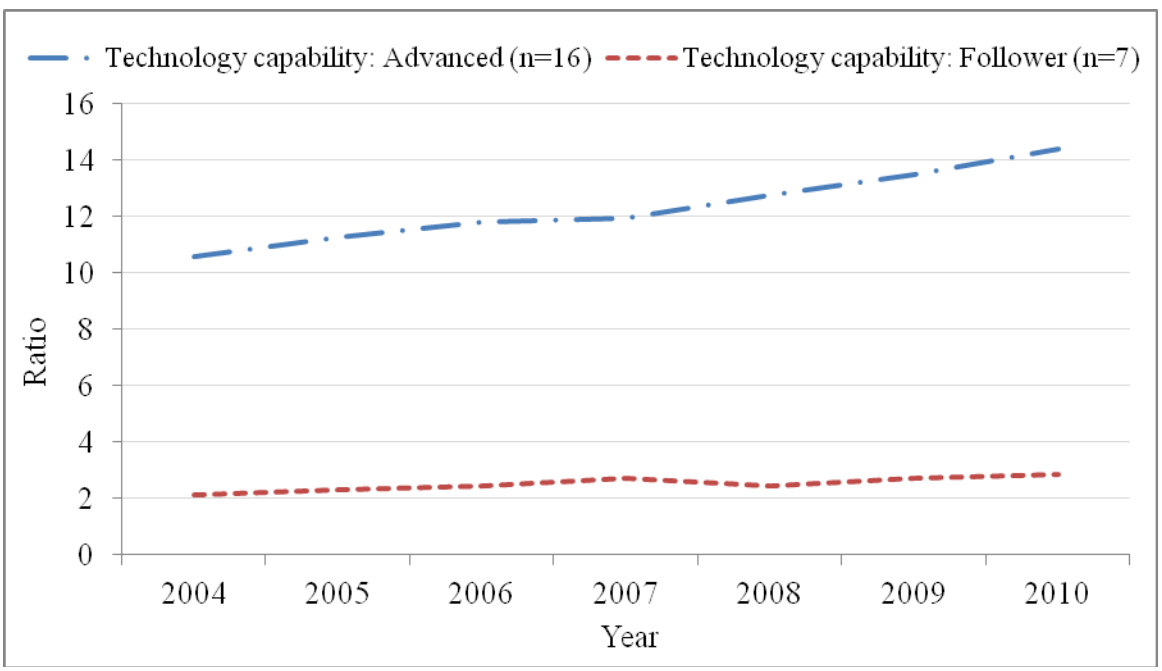


Figure 10. Mean Ratio of International STEM Enrollment to National STEM Enrollment by Country of Technological Capability: Advanced Versus Followers, 2004-2010



Descriptive Statistics

Table 3 presents descriptive statistics on the characteristics of the 23 host countries analyzed. The mean of international STEM enrollment shows an upward trend, from some 23,000 in 2004 to 32,000 in 2010. Similarly, the mean ratio of international STEM enrollment to national STEM enrollment — also indicates a steady growth (from 8.0 to 10.7).

An important descriptive variable was the availability of English-language instruction in tertiary education programs. According to OECD (2011a), among these 23 host countries, five of them (22%) rely on English-language instruction in all, or nearly all, tertiary education programs (Australia, Canada, New Zealand, the UK, and the US); four of them (Denmark, Finland, the Netherlands, and Sweden) rely on English-language instruction in many tertiary education programs; and nearly half of them (including Belgium, the Czech Republic, France, Germany, Hungary, Japan, Norway, Poland, Portugal, Switzerland, and Turkey) rely on English-language instruction in some tertiary education programs. By contrast, in Austria, Italy, and Spain, almost no tertiary education programs are offered in English.

Technological capability is another important variable. Countries vary in their technological capability. There are 16 technologically advanced countries (featuring high infrastructure and skills and high innovation), and the remaining seven countries are followers in technological capability (featuring medium-high infrastructures skills and low innovation). None of the countries analyzed in the Pull Model falls into the category of technologically marginalized countries (featuring low infrastructures skills and low innovation).

National students’ participation rate in STEM programs is another informative variable. The number of national students enrolled in STEM programs in domestic higher education institutions (in 23 OECD countries) has increased slightly (per 1,000 population corresponding to tertiary education, 134 students studied in STEM programs in 2004 and 140 in 2010).

With respect to the academic reputation of universities, the proportion of universities ranked in the top 500 of Academic Ranking of World Universities (ARWU) decreased from 19.48 to 18.3 within the seven-year time-span on which this study focused. The decrease does not necessarily imply that the academic reputation of universities in these 23 OECD countries has dropped. The decrease is largely the result of the gradual improvement of the scientific research outputs of universities in non-OECD countries, improvement that allowed some of these countries to enter the top 500 ranking list. For instance, in 2005 there were 168 universities in the US ranked in the top 500 ARWU, four universities in Brazil, and eight universities in China. In 2010, the numbers for Brazil and China increased to six and 22 respectively, whereas the number for the US decreased to 154. Consequently, the proportion of universities in OECD countries that are ranked in ARWU has reduced slightly.

Generally, these 23 countries have gradually increased financial resources for R&D activities, as indicated by gross domestic expenditure on R&D as a percentage of gross domestic products (GDP) in a country, which is one of the most frequently studied indicators in the field of research and innovation. This variable increased from 1.96% in 2004 to 2.17% in 2010.

Table 3

The Pull Model: Descriptive Statistics of the Variables

Variable	Name	N	Mean by year 2004	2005	2006	2007
Dependent	Number of international STEM enrollment	161	23,437.39	26,071.78	26,822.96	27,523.00
	Ratio of international STEM enrollment to national STEM enrollment	161	8.00	8.52	8.96	9.13
Independent	**Higher education system**					
	English-language instruction (as of 2005-2010)[a]	161	-	-	-	-
	National students' participation rate in STEM programs	161	133.91	132.35	132.48	133.17
	Proportion of universities ranked top 500 Academic Ranking of World Universities	161	19.48	19.30	19.22	19.30
	Science and technology intensity					
	Technological capability: Advanced (as of 2000)[a]	161	-	-	-	-
	Technological capability: Followers (as of 2000)[a]	161	-	-	-	-
	Gross expenditure on R&D as a percentage of GDP	161	1.96	1.96	1.96	2.04
	Demographic change					
	Percentage of population aged 65 or more to total population	161	15.13	15.22	15.22	15.43
Control	Tertiary enrollment (million)	161	1.82	1.85	1.87	1.90

Note. Dash indicates time invariance across the years studied.
[a]Indicator.

Table 3 (Continued)

Descriptive Statistics of Variables in Analyses for 23 OECD Host-Country Characteristics

	Mean by year			Total	SD
Name	2008	2009	2010	(all years)	
Number of international STEM enrollment	28,533.35	30,272.96	31,873.95	27,765.25	47,660.66
Ratio of international STEM enrollment to national STEM enrollment	9.61	10.22	10.73	9.30	8.60
Higher education system					
English-language instruction (as of 2005-2010)[a]	-	-	-	0.22	0.41
National students' participation rate in STEM programs	134.00	135.61	140.00	134.47	50.42
Proportion of universities ranked top 500 Academic Ranking of World Universities	18.87	18.61	18.30	19.01	32.89
Science and technology intensity					
Technological capability: Advanced (as of 2000)[a]	-	-	-	0.70	0.46
Technological capability: Followers (as of 2000)[a]	-	-	-	0.30	0.46
Gross expenditure on R&D as a percentage of GDP	2.13	2.17	2.17	2.06	0.88
Demographic change					
Percentage of population aged 65 or more to total population	15.74	15.87	16.09	15.53	3.06
Tertiary enrollment (million)	1.92	1.99	2.13	1.92	3.65

Note. Dash indicates time invariance across the years studied.
[a]Indicator.

With respect to demographic variables, most of these 23 countries feature aging populations (meaning that older individuals represent a larger share of the total population), except for Belgium, Norway, and Spain. The mean percentage of countries with populations aged 65 and above has increased from 15.13% in 2004 to 16.09% in 2010. A few counties have even more rapidly aging populations than others. For instance, in Austria, Denmark, Finland, Germany, Japan, and the Netherlands, the percentage of the population aged 65 and above increased by a factor of at least 1.1 between 2004 and 2010.

In addition to the variables pertaining to the host countries presented above, one potential variable is worthy of note: the stay rate of international students in the host country. The stay rate is estimated as the ratio of the number of international students who have changed from student-related status and residency to some other status in the host country (e.g., work visas, citizenship, permanent residency) to the number of students who have not renewed their permits (OECD, 2010b). As an example, in 2008, international students in Canada had a high stay rate at 33% (Table 4), meaning that one-third of international students in Canada changed their student status to permanent residency or to another status that allowed them to stay in Canada after their graduation. In many cases, countries with high stay rates of international students have immigration policies that encourage the temporary or permanent immigration of international students (OECD, 2011b).

The information about the stay rate of international students is useful because it indicates the relationship between the potential benefits of immigration and the mobility of international STEM students. Such data are only available in 10 host countries however, and cannot be expanded to all 23 countries, so this variable will not be entered into the regression estimate in the analysis later.

While an investigation of relevant variables indicated that the number of international STEM students hosted increased from 2004 to 2010, the specific host-country characteristics associated with greater international STEM enrollment need to be examined. The following section presents analytical results of the correlation between variables of host-country characteristics and international STEM enrollment.

Table 4

Percentage of International Students who Changed Status and Stayed on in Selected Host Countries, 2008 or 2009

Host country	Year	Stay rate	Host country	Year	Stay rate
Canada	2008	33	Norway	2008	23
France	2008	32	Finland	2009	22
Czech Republic	2009	31	New Zealand	2008	21
Australia	2008	30	Japan	2008	21
Germany	2008	26	Spain	2009	19
UK	2009	25	Austria	2008	17

Source: OECD (2010b).

Correlation Analyses

A correlation analyses was performed to determine whether multicollinearity existed and required adjustments to variables entered in the regression estimation. The analyses indicated positive correlations for international STEM enrollment and English-language instruction for all, or nearly all, programs (r = 0.587, p< .001), as illustrated in Table 5 In other words, English-speaking countries host more international STEM students than their counterpart countries. In addition, international STEM enrollment and the proportion of universities ranked in the top 500 Academic Ranking of World Universities (ARWU) are positively related, and the relation is statistically significant (r = 0.270, p <.001).

Analyses also revealed a positive correlation and statistical significance for international STEM enrollment and two other independent variables: countries with advanced technological capability (r=0.406, p<.001), and gross expenditure on research and development (R&D) as a percentage of gross domestic products (r=0.360, p<.001).

Ultimately, the correlation analyses indicated that three independent variables are highly correlated: (a) advanced technological capability, (b) the proportion of universities ranked in the top 500 ARWU, and (c) gross domestic expenditure on R&D as a percentage of gross domestic products (GERD as a percentage of GDP). To avoid statistical model instability in estimation often caused by high collinearity (i.e., very high correlation among independent variables), this study used GERD as a percentage of GDP to represent the research intensity of a host country and excluded independent variables that were highly correlated in the same regression estimation.

Table 5

The Pull Model: Correlation Matrix

Variable		Name	1	2	3	4	5	6	7	8
Dependent	1	Log number of international STEM enrollment	1.000							
Independent	2	English-language instruction [a]	0.587***	1.000						
	3	National students' participation rate in STEM programs	-0.136	-0.164*	1.000					
	4	Proportion of universities ranked in top 500 Academic Ranking of World Universities	0.270**	0.389***	-0.007	1.000				
	5	Technological capability: Advanced[a]	0.406***	0.349***	-0.077	0.510***	1.000			
	6	Gross expenditure on R&D as a percentage of GDP	0.360***	-0.016	0.236**	0.311***	0.687***	1.000		
	7	Percentage of population aged 65 or over to total population	0.111	-0.348***	0.259**	0.120	0.150	0.346***	1.000	
Control	8	Log tertiary enrollment	0.633***	0.317***	-0.160*	-0.220**	-0.095	-0.013	-0.072	1.000

Note. [a]Indicator.
*p< .05. ** p< .01. *** p< .001.

Panel Data Analyses

To answer the study's research questions, regression models for panel data were employed to examine the relationship between international STEM enrollment and host-country characteristics. International STEM enrollment, the dependent variable, was measured in two ways: the log number of international STEM students with a control variable of tertiary enrollment and the log ratio of international STEM enrollment to national STEM enrollment.

Table 6 displays the outputs of the fixed- and random-effect estimations for the relationship between international STEM enrollment and host-country characteristics. Three statistical models are presented. The dependent variable for Model 1 is log international STEM enrollment, whereas the dependent variable for Models 2 and 3 is log ratio of international STEM students to national STEM enrollment. These three models contain slightly different sets of independent variables. Model 1 is distinguished by the inclusion in Model 1 of technological capability: advanced and the exclusion of two highly correlated variables (the proportion of universities ranked in the top 500 Academic Ranking of World Universities and the gross expenditure on R&D as a percentage of gross domestic products). Similarly, the same arrangement of independent variables was applied to distinguish Models 2 and 3. The control variable, log tertiary enrollment, was removed from Model 2 and Model 3, since the ratio had taken tertiary enrollments into account. For each model, the Breusch-Pagan Lagrange multiplier (LM) test and F-test were performed to examine whether random effects or fixed effects exist, and the results showed that both group-specific fixed effects and random effects existed in the models.

Table 6

The Pull Model: Panel Data Models of Regressions on the Log International STEM Enrollment and on the Log Ratio of International STEM Students to National STEM Enrollment (N = 161), Years 2004-2010

	One-way group effect model		
	Log international STEM enrollment	Log ratio of international STEM enrollment to national STEM enrollment	
	Random Effects Model 1	Random Effects Model 2	Random Effects Model 3
English-language instruction [a]	1.038***	0.953**	1.175***
	(0.442)	(0.363)	(0.328)
National students' participation rate in STEM programs	-0.001***	-0.005**	-0.005**
	(0.002)	(0.002)	(0.002)
Proportion of universities ranked in top 500 Academic Ranking of World Universities			0.018*
			(0.009)
Technological capability: Advanced[a]	1.063***	0.974**	
	(0.372)	(0.332)	
Gross expenditure on R&D as a % of GDP			0.016
			(0.053)
Percentage of population aged 65 or over	0.062*	0.058*	0.068*
	(0.031)	(0.030)	(0.031)
Log tertiary enrollment	0.806***		
	(0.132)		
Intercept	-3.625**	0.675	0.878
	(1.837)	(0.541)	(0.527)
Goodness-of-fit statistics			
Wald chi2 test	78.76***	36.53***	33.62***
Degrees of freedom	134	129	127
R^2	0.946	0.897	0.868
ρ	0.947	0.933	0.919
SSE	7.012	0.801	1.092*
SEE	0.168	0.167	0.182
$\hat{\sigma}_u$	0.711	0.621	0.600
θ	0.906	0.892	0.889
Effect Test	404.310***	368.510***	344.98***
N	161	161	161

Note. Standard errors in parenthesis.
[a]Indicator.
*p < .05. ** p < .01. *** p <.001.

To decide whether the random effects models were favored over the fixed effects models in individual models, a Hausman test was conducted. The results of the Hausman test indicated that the chi-squared for Model 1, Model 2, and Model 3 was small enough to not reject the null hypothesis. This suggested the random effects models as better-fitting for Models 1, 2, and 3.

As illustrated in Table 6, the use of absolute numbers (log international STEM enrollment) as the dependent variable in Model 1, and the use of ratios (log ratio of international STEM students to national STEM enrollment) as the dependent variable in Models 2 and 3 yielded similar results. More specifically, the results of all models showed that the coefficients of the variables that reach a significance level, and their directions of relation (positive or negative), were consistent across the four models.

The panel data analyses highlight the relationship between English-language instruction in tertiary education and higher enrollment of international STEM students. Compared with their counterpart countries, and holding all other variables constant, countries in which English-language instruction is the norm for all or most tertiary education programs enroll more international STEM students ($p<.05$).

Panel data analyses also reveal that national students' participation rate in STEM programs is negatively related to international STEM enrollment, and the negative relation is significant.

According to the panel data analyses, the host country’s technological capability also matters. Compared with their counterpart countries (i.e., followers in technological capability with medium-high infrastructure and skills and low innovation), countries with advanced technological capability (with high infrastructure and skills and high innovation) enroll substantially more international STEM students, holding all other variables constant.

Host countries that have high percentages of population aged 65 or above (as a measure of aging populations) are more likely to enroll more international STEM students, according to the data panel analysis.

Another characteristic, the proportion of universities ranked in top 500 Academic Ranking of World Universities, was found to have positive relationship with international student enrollment.

The estimate results indicate that the capacity of a higher education system to enroll STEM students makes a difference in international STEM enrollment. As the size of higher education enrollment goes up, so does international STEM enrollment.

Regarding the measure of goodness-of-fit, a there is no generally accepted standard for the measures of goodness-of-fit in panel data models (Kunst, 2009). This study uses the ratio of individual specific error variance to the composite error variance (shown as *rho* in STATA output tables) as a goodness-of-fit for random effects models (Park, 2011). Table 6 shows that the random effects estimation models have high values of ρ (0.919~0.947), suggesting that in the random-effect model in Model 1, for instance, the individual specific error can explain 94.7% of entire composite error variance.

Analysis II: Push Model

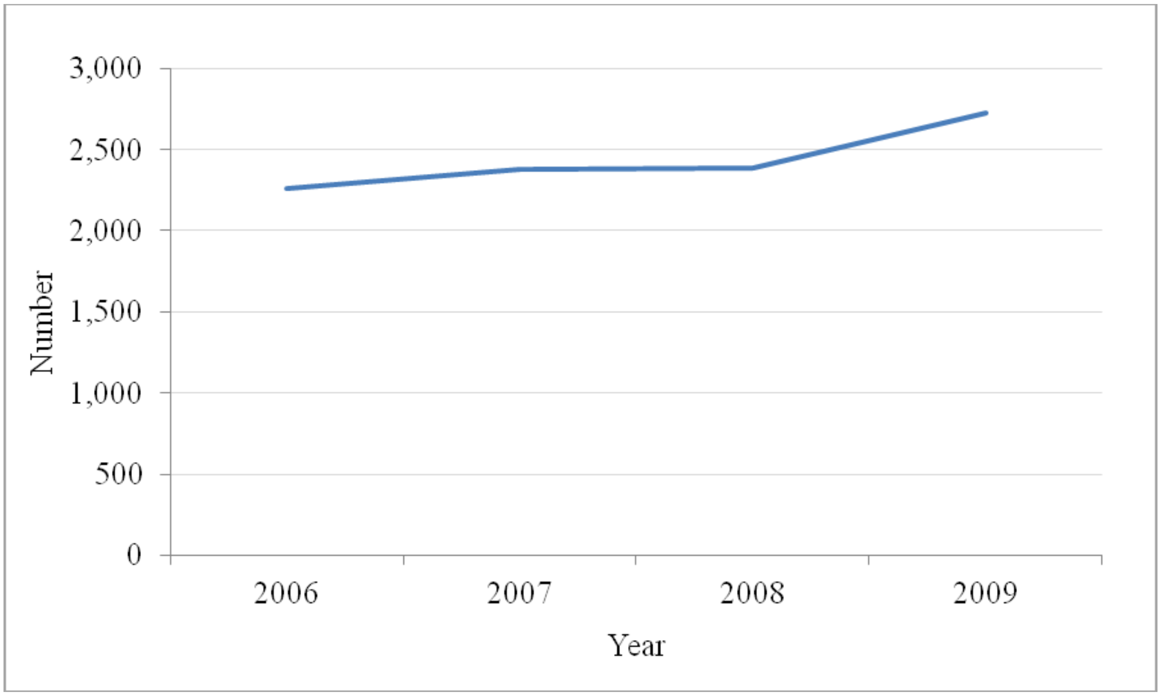
The Push Model examines how four aspects of students' home countries—human capital determinants, higher education capacity and academic reputation, national science and technology intensity, and the state of civil and political freedom—are associated with student demand for overseas STEM education in Australia, the UK, and the US. The Push Model also investigates how the bilateral links between a host country and students' home countries are related to the flows of STEM students to Australia, the UK, and the US.

To examine the characteristics of students' home countries in relation to students' decisions to study STEM education abroad, several analyses were conducted. Specifically, after assessing the properties and quality of the panel data (discussed in Chapter Three), trend analyses and descriptive analyses were performed to understand the profiles of students' home countries analyzed in the Push Model. Then, correlations between variables were tested in order to determine whether multicollinearity existed and required adjustments to variable groupings and planned analyses. Finally, the panel data analyses were conducted.

Trend Analyses

Trend analyses were performed to get a general picture of student demand for overseas STEM education (measured by the number of students from a country enrolled in tertiary-level STEM programs in Australia, the UK, and the US). Figure 11 shows that the mean number of students from a country who were enrolled in tertiary-level STEM programs in Australia, the UK, and the US has increased by a factor of 1.2, from 2,263 in 2006 to 2,729 in 2009.

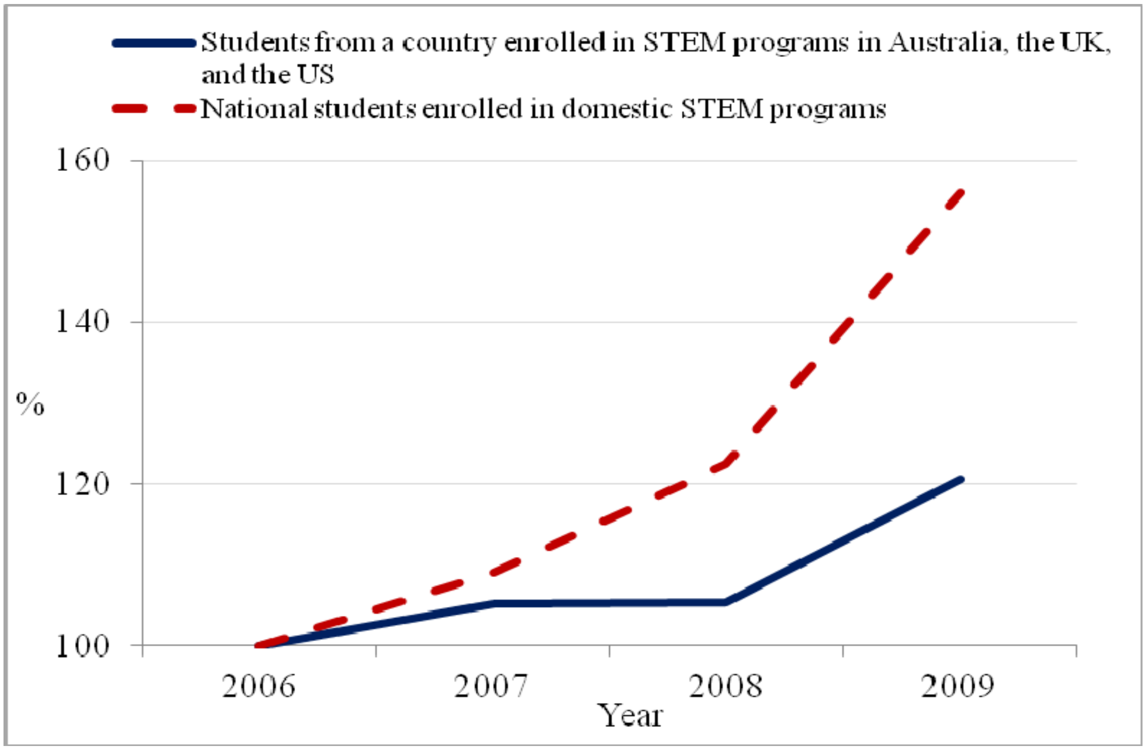
Figure 11. Mean Numbers of Students from a Country Enrolled in Tertiary-Level STEM Programs in Australia, the UK and the US, 2006-2009



During the same time span (2006 - 2009), the growth in the number of students enrolled in STEM programs in their home countries (domestic STEM enrollment) occurred at a faster rate compared with that of their counterparts from the same home countries enrolled in STEM programs in Australia, the UK, and the US (outbound STEM enrollment), as illustrated in Figure 12. Because domestic STEM enrollment increased faster than outbound STEM enrollment in the three host countries, the ratio of these two student bodies (abroad to domestic) gradually declined between 2006 and 2009 (see Figure 13).

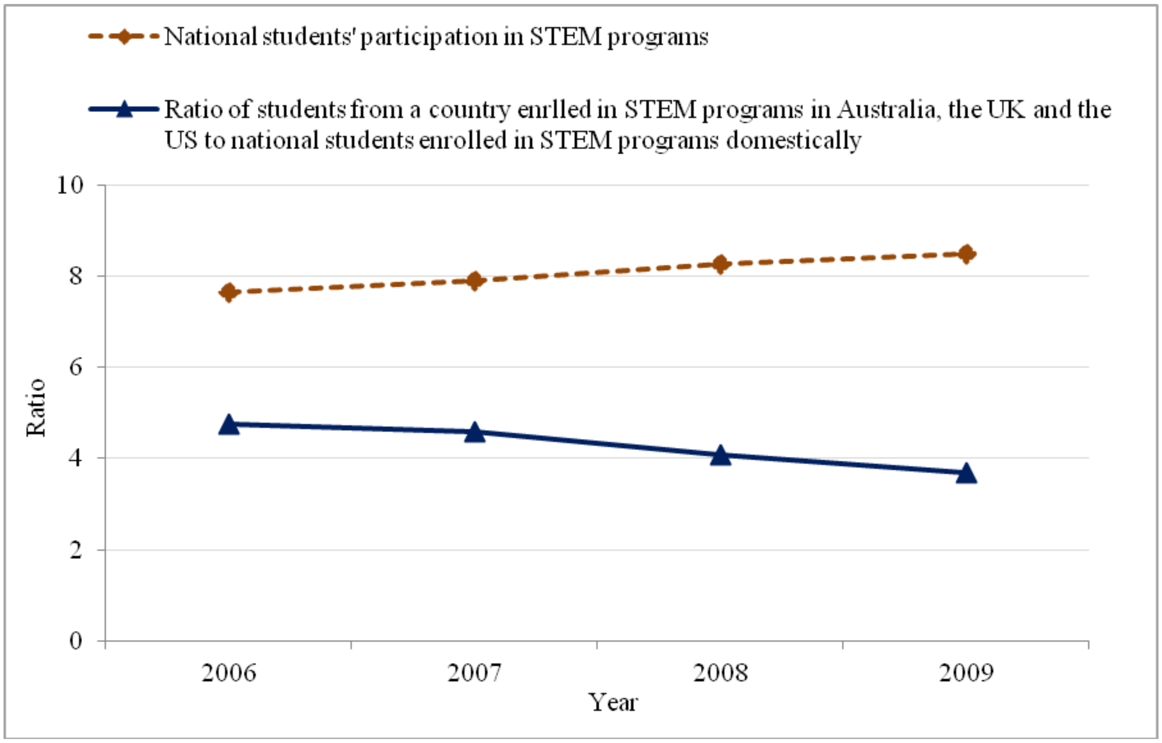
The trend analyses examined student demand in both absolute numbers and ratios; and the ratio takes enrollment in students' home countries into account. The results show that Asia has the greatest demand, in terms of both absolute numbers and ratios, for the tertiary-level STEM education in Australia, the UK, and the US (Figure 14 and Figure 15). For every 100 STEM students who study in domestic higher education systems in Asia, approximately six students studied abroad in tertiary STEM programs in Australia, the UK, and the US. Following Asia, Africa has a high ratio of outbound-to-local STEM enrollment of 3 (Figure 15), even though Africa has the lowest number of students enrolled in tertiary-level STEM programs in Australia, the UK, and the US.

Figure 12. A Comparison between Growth in Mean Numbers of Students Enrolled in Overseas Tertiary-Level STEM Programs (in Australia, the UK and the US) and Growth in Mean Numbers of Domestic STEM Enrollment, 2006-2009



Note. Base year is 2006.

Figure 13. Trends in National Students' Participation Rate in STEM Programs Domestically and in the Ratio of Outbound-to-Local STEM Enrollment, 2006-2009



Note. National students' participation rate in STEM programs is the number of national students enrolled in domestic tertiary-level STEM programs regardless of age divided by the typical age population corresponding to higher education.
The ratio is the number of students enrolled in overseas STEM programs in Australia, the UK, and the US) to the number of students enrolled in domestic STEM programs.

Figure 14. Mean Number of Students by Continent Enrolled in Tertiary-Level STEM Education in Australia, the UK and the US, 2006-2009

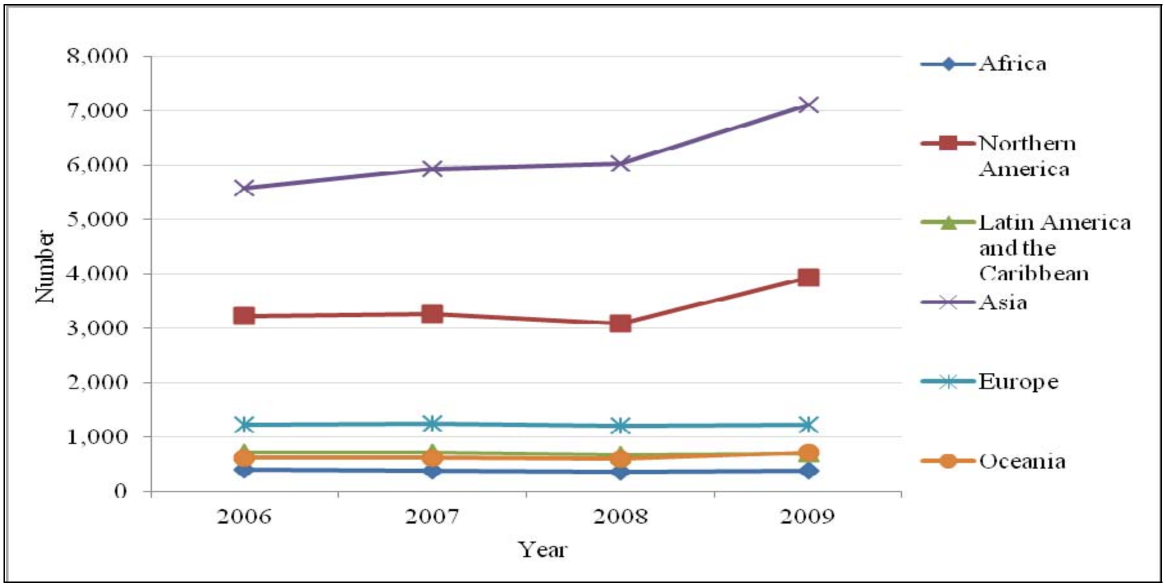
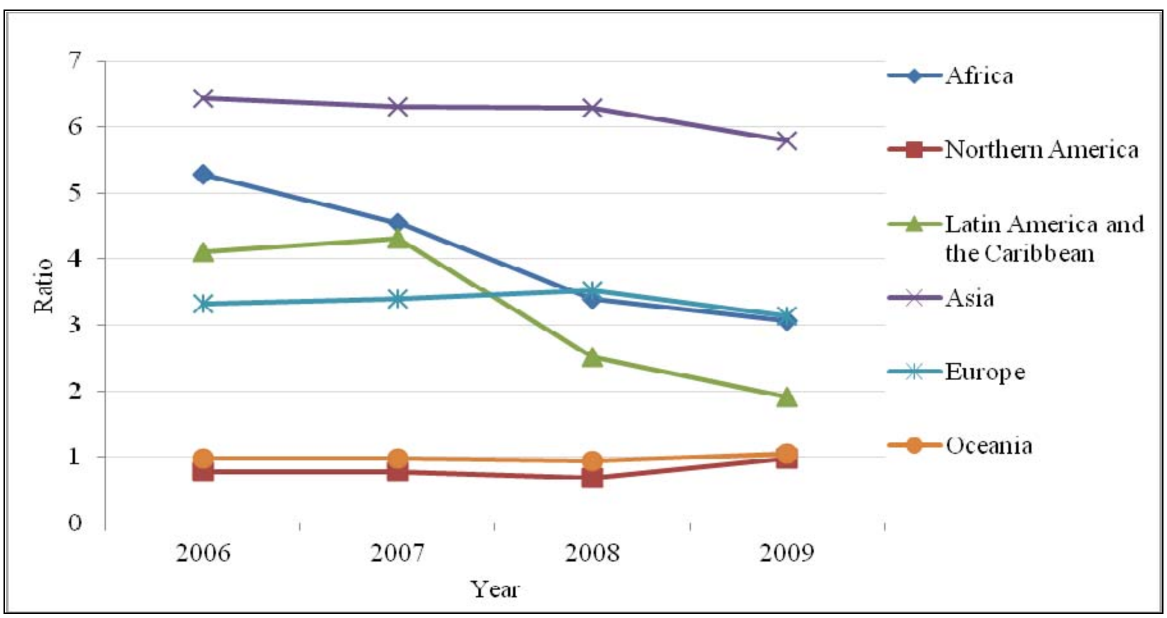


Figure 15. The Mean Ratio of Outbound STEM Students to National STEM students, 2006-2009



In summary, the trend analyses revealed two patterns. First, the population of STEM students who studied abroad (in Australia, the UK, and the US) grew steadily (by a factor of 1.2) between 2006 and 2009. This population did not grow, however, as fast as the population in STEM education in domestic higher education systems. The development suggests that, generally, higher education systems in most of students' home countries have enhanced their capacity to enroll more students to study STEM education. Second, student demand for overseas STEM education varies by continent. Students from Asia, both in absolute numbers and ratios, exhibit the greatest demand for tertiary-level STEM education in Australia, the UK and the US.

Descriptive Analysis

Table 7 presents descriptive statistics on the characteristics of students' home countries. In total, 124 countries were analyzed in this study, including countries in Africa (31), North America (2), Latin America (16), Asia (37), Europe (36), and the Oceania (2). The dependent variable -- the mean number of students from a country enrolled in tertiary-level STEM programs in Australia, the UK and the US—shows a steadily growing trend between 2006 and 2009, with a mean of 2,438.75 and a large standard deviation (8,596.87). This section highlights students' home countries in four aspects (human capital determinants, the higher education system, the science and technology intensity, and the state of civil and political freedom).

Table 7

The Push Model: Descriptive Statistics of Variables

Variables		Mean by year				Total	Standard Deviation
Home-country variable	N	2006	2007	2008	2009	(all years)	
Number of students from a country enrolled in tertiary-level STEM programs in Australia, the UK, or the US	496	2,263.21	2,378.21	2,384.15	2,729.43	2,438.75	8,596.87
Human capital determinants							
Gross national income *per capita* PPP	496	14,871.73	15,742.9	16,304.92	15,802.9	15,680.61	16,088.34
Emigration rate of tertiary-educated people from a country to OECD countries (as of 2005)	492	-	-	-	-	11.41	11.91
Proportion of emigrants from a country to OECD countries who have attained tertiary education (as of 2005)	492	-	-	-	-	33.39	13.05
Higher education system							
National students' participation rate of in STEM programs	496	7.67	7.92	7.92	8.50	8.09	7.02
Unavailability of doctoral programs [a]	496	0.14	0.13	0.13	0.11	0.13	0.33
Proportion of universities ranked in top 500 Academic Ranking of World Universities	496	0.04	0.04	0.04	0.03	0.04	0.08
Science and technology intensity							
Technology capability: Advanced (as of 2000)[a]	496	-	-	-	-	0.15	0.35
Technology capability: Followers (as of 2000)[a]	496	-	-	-	-	0.47	0.50
Technology capability: Marginalized(as of 2000)[a]	496	-	-	-	-	0.39	0.49

Table 7 (Continued)

Variables	N	Mean by year 2006	2007	2008	2009	Total (all years)	Standard Deviation
Gross domestic expenditure on R&D as a percentage of gross domestic products	400	0.90	0.91	0.94	0.98	0.93	1.00
Number of science and technology articles per 100,000 inhabitants	492	10.02	10.11	10.23	10.22	10.15	15.80
Civil and political freedom							
Free in the preceding year (as of 2005-2008)[a]	496	-	-	-	-	0.49	0.50
Partially free in the preceding year (as of 2005-2008)[a]	496	-	-	-	-	0.29	0.45
Not free in the preceding year (as of 2005-2008)[a]	496	-	-	-	-	0.22	0.41
Continent							
Africa[a]	496	-	-	-	-	0.25	0.43
North America[a]	496	-	-	-	-	0.02	0.13
Latin America[a]	496	-	-	-	-	0.13	0.34
Asia[a]	496	-	-	-	-	0.30	0.46
Europe[a]	496	-	-	-	-	0.29	0.45
Oceania[a]	496	-	-	-	-	0.02	0.13
Control variable							
Population (100,000)	496	479.44	484.70	489.97	500.44	488.64	1,620.68

Note. Dash indicates time invariance across the years studied.
[a]Indicator.

Human capital determinants. An important descriptive variable is gross national income *per capita*), purchasing power parity (GNI per capita PPP) (as a measure of funding available for studying abroad), which indicates national wealth. The range of national wealth among the 124 countries is wide, with a mean of GNI *per capita* PPP of 15,680 and a large standard deviation of 16,088.

Two informative variables describe the extent to which the emigration of highly education citizens. In the 124 countries analyzed, the mean of a country's emigration rate of people who have attained tertiary education and emigrated to OECD countries is 11.41%, meaning that on average, for every 100 people in a country who have attained tertiary education, 11 emigrate to OECD countries. The other finding indicates that, on average, out of every 100 people from the same country of origin who emigrated to OECD countries, 33 have attained tertiary education.

Higher education system. Higher education systems in students' home countries were analyzed and found to differ in terms of student participation rate in STEM programs, unavailability of doctoral programs, and academic reputation. First, the participation rate of national students in STEM programs increased from 7.67% to 8.50% between 2006 and 2009. Such an increase indicates that more national students were enrolled in tertiary-level STEM programs domestically, which also suggests that higher education systems provide more educational opportunities for students to study STEM education in their home countries. Though educational opportunities for tertiary-level STEM education in most countries have improved, 16 out of the 124 countries analyzed do not offer doctoral degree programs.

With respect to the academic reputation of universities in students' home countries, the mean proportion of universities ranked in the top 500 Academic Ranking of World Universities is small at 0.04. The small mean is a consequence of the fact that only 500 of approximately 15,000 universities worldwide (UNESCO, 2013) are ranked, and only 37 countries of the 124 countries analyzed in this study have universities ranked in the top 500 Academic Ranking of World Universities.

Scientific and technological capability. Regarding the scientific and technological capabilities of students' home countries, among the 124 countries analyzed, 15% have advanced technology capability; 47% are followers in technology capability; and 39% have marginalized technology capability. Moreover, individual countries have quite different levels of investment in research and development activities (R&D) (as explained above, this measure is an important component of building a country's technological capabilities). Among the 100 countries where such data was available, GERD as a percentage of GDP ranges from 0.02% to 4.84%. An important output of R&D activities is scientific publications (Castellacci & Archibugi, 2008; OECD, 2008c). The mean number of science and technology articles per 100,000 inhabitants in the 124 countries analyzed is 10.15.

Civil and Political Freedom. With respect to the state of civil and political rights in students' home countries in the preceding year, among the 124 countries analyzed, 61 of them are rated as "free," 36 are "partly free," and 27 are "not free".

While descriptive analyses and trend analyses show that the numbers of STEM students rose between 2006 and 2009, they do not reveal correlations between the characteristics of students' home countries and higher outflows of STEM students to Australia, the UK, or the US. The next section presents analytical results of correlations among variables and the panel data analyses.

Correlation Analyses

A correlation analyses (Table 8) was performed to determine whether multicollinearity existed and required adjustments to variables entered in regression estimation. It is noted that, as discussed in the trend analysis, student demand for overseas STEM education (the dependent variable) can be measured in two ways: (a) the number of students abroad (i.e., outbound STEM enrollment), and (b) the ratio of outbound STEM students to national STEM students (i.e., outbound STEM enrollment divided by the enrollment of national students in domestic STEM programs). The denominator of the ratio is also an independent variable. Thus, this study used numbers (rather than the ratio) as the dependent variable. The following section highlights the results of the correlation analyses.

The analysis indicates positive correlations between national wealth and student demand for overseas STEM education in Australia, the UK, and the US, and the relation is statistically significant ($r = 0.362$, p<.001). Student demand for overseas STEM education is positively related to two migration variables (as a measure of expected benefits of studying abroad). The correlation between the outflows of STEM students and the emigration rate of tertiary-educated people to OECD countries is positive (r = -.101p< .05), and the correlation with the proportion of emigrants to OECD countries who have attained tertiary education is also positive (r =.379, p<.001).

Table 8

Push Model: Correlation Matrix

Variable		Name	1	2	3	4	5	6
Dependent	1	Log number of outbound STEM students in Australia, the UK and the US	1.000					
Independent	2	Gross national income per capita PPP[a]	0.362***	1.000				
	3	Emigration rate of the tertiary educated people	-0.101*	-0.140**	1.000			
	4	Proportion of emigrants who have attained tertiary education	0.379***	0.249***	-0.239***	1.000		
	5	National students' participation rate in STEM programs domestically	0.389***	0.450***	-0.212***	0.033	1.000	
	6	Unavailability of doctoral program	-0.450***	-0.199***	0.242***	-0.149***	-0.366***	1.000
	7	Proportion of universities ranked in top 500 ARWU[c]	0.262***	0.560***	-0.078	0.260***	0.396***	-0.161***
	8	Scientific and technical journal articles per 100,000 inhabitants	0.265***	0.714***	-0.150***	0.170***	0.594***	-0.235***
	9	Technology capability: advanced[b]	0.175***	0.554***	-0.150***	0.244***	0.298***	-0.156***
	10	Technology capability: Followers[b]	0.158***	0.184***	-0.106*	-0.094*	0.404***	-0.244***
	11	Technology capability: Marginalized[b]	-0.288***	-0.589***	0.217***	-0.080	-0.630***	0.363***
	12	Civil and political freedom: Free in the preceding year[b]	0.169***	0.378***	0.039	0.014	0.371***	-0.236***
	13	Civil and political freedom: Partially free in the preceding year[b]	-0.115*	-0.271***	0.087	-0.024	-0.205***	0.107*
	14	Civil and political freedom: Not free in the preceding year[b]	-0.078	-0.160***	-0.142**	0.010	-0.224***	0.168***
Control	15	Log population	0.594***	-0.144**	-0.294***	0.197***	0.103*	-0.337***

Note. [a]Purchasing Power Parity.[b]Indicator. [c]The Academic Ranking of World Universities.
p* < .05. ** *p* < .01. * *p* <.001.

Table 8 (Continued)

	Name	7	8	9	10	11	12	13	14	15
7	Proportion of universities ranked in top 500 ARWU[c]	1.000								
8	Scientific and technical journal articles per 100,000 inhabitants	0.826***	1.000							
9	Technology capability: advanced[b]	0.617***	0.815***	1.000						
10	Technology capability: Followers[b]	-0.111*	-0.107*	-0.386***	1.000					
11	Technology capability: Marginalized[b]	-0.333***	-0.481***	-0.328***	-0.745***	1.000				
12	Civil and political free in the preceding year[b]	0.274***	0.520***	0.421***	0.059	-0.365***	1.000			
13	Civil and political partially free in the preceding year[b]	-0.101*	-0.304***	-0.264***	0.041	0.148***	-0.627***	1.000		
14	Civil and political not free in the preceding year[b]	-0.220***	-0.296***	-0.219***	-0.117**	0.278***	-0.520***	-0.339***	1.000	
15	Log population	0.064	-0.016	0.071	-0.098*	0.049	-0.081	-0.022	0.122**	1.000

Note. [a]Purchasing Power Parity.[b]Indicator. [c]The Academic Ranking of World Universities.
*p < .05. ** p < .01. *** p <.001.

Student demand for overseas STEM education is also positively related to the participation rate of national students in domestic tertiary-level STEM programs ($r = 0.389$, $p<.001$) and the proportion of universities ranked in top 500 Academic Ranking of World Universities ($r = 0.262$, $p<.001$). The correlation analyses indicated that student demand for overseas STEM education is negatively associated with countries with an absence of doctoral education ($r = -0.450$, $p<.001$).

The correlation analysis also shows that student demand for overseas STEM education is significantly associated with a country's science and technology intensity. The log of outbound STEM enrollment is positively related to (a) the number of science and technology journal articles *per capita* and (b) high- or medium-level technological capabilities; however, the outflow of STEM students is negatively related to marginalized technological capability.

According to the correlation analysis, the level of civil and political freedom in students' home countries is associated with the outflows of STEM students. Compared with their counterpart countries, countries with civil and political freedom have more students pursuing STEM education in Australia, the UK, and the US.

It is worth noting that a number of independent variables are correlated. Particularly, national wealth (gross national income *per capita*) is highly and positively correlated with: (a) national students' participation rate in domestic tertiary-level STEM education, (b) the proportion of universities ranked in top 500 Academic Ranking of World Universities , (c) science and technology articles per 100,000 inhabitants (as a measure of research performance), and (d) national technological capability. This correlation suggests that wealthier countries are more likely to have a higher enrollment ratio for tertiary-level STEM education and to have relatively more universities with high academic reputations. Wealthier countries tend to have advanced technological capability and produce more science and technology articles.

To avoid statistical model instability in estimation that can be caused by multicollinearity, independent variables that are highly correlated were examined in separate statistical models, as presented in the following panel data analyses.

Panel Data Analyses

To answer the study's research questions, panel data models were employed to examine the relation between student demand for tertiary-level STEM education in Australia, the UK, and the US and the characteristics of students' home countries. As discussed in the previous chapter, for the Push Model, random effects estimations were more suitable for this analysis than fixed effects estimations because the individual dimension is large relative to the time dimension; and thus, group effects can be viewed as random (Park, 2011).

Table 9 displays the output of random effects estimations for the relation between student demand for overseas STEM education in three host countries (Australia, the UK, and the US) and the characteristics of students' home countries. Four random effects estimations were selected and presented. All four models used the same dependent variable (i.e., the log number of students who study abroad in STEM programs in Australia, the UK and the US) with a different set of independent variables. Model 5 included gross national income *per capita*, which is frequently examined in previous research to test income effect on demand for overseas education. However, because gross national income *per capita* is highly correlated with four variables of interest (national students' rate of participation in STEM programs, the proportion of universities ranked in top500 Academic Ranking of World Universities, technological capability, and science and technology journal articles *per capita*), these correlated variables are absent from Model 4 and included instead in Model 5, Model 6, or Model 7.

For each model, the Breusch-Pagan Lagrange multiplier (LM) test was performed to examine whether random effects exist, and the results show that random group effects existed in these four models.

The results of random effects estimations in Model 4 show a positive relationship between national income *per capita* (as a measure of funding available for study abroad) and outbound STEM enrollment. Holding all other variables constant, countries that have high national income *per capita* exhibit high outbound STEM enrollment.

The analyses also reveal that a coutry's emigration of tertiary-educated citizens to OECD countries (as a measure of expected benefits of study abroad) is related to the outflow of STEM students. The results of random effects estimations showed that the high emigration rate of citizens that have attained tertiry education or the high proportion of emigrants who have attained tertiary educated is associated with large outbound STEM enrollments.

Table 9

The Push Model: Panel Data Models of Regressions on Log Outbound STEM Enrollment in Australia, the UK and the US (N = 496), Years 2006-2009

	One-way random group effect models			
	Model 4	Model 5	Model 6	Model 7
Gross national income *per capita* PPP (US$1000)	0.035*** (0.005)			
Emigration rate of tertiary-educated people to OECD countries	0.034*** (0.008)	0.025** (0.009)	0.028** (0.009)	0.033*** (0.009)
Proportion of emigrants to OECD countries who have attained tertiary education	0.035*** (0.008)	0.042*** (0.008)	0.042*** (0.008)	0.041*** (0.008)
National students' participation rate in STEM programs		0.036** (0.010)		
Unavailability of doctoral programs[a]	0.187 (0.118)	0.117 (0.125)	0.171 (0.121)	0.216 (0.118)
Proportion of universities ranked in top 500Academic Ranking of World Universities			3.261** (1.083)	
Technology capability: Advanced[a]		0.244 (0.297)		
Technology capability: Follower[a]	0.845*** (0.190)		1.088*** (0.206)	1.141*** (0.207)
Scientific & technical journal articles per 100,000 inhabitants				0.031*** (0.006)
Civil and political freedom: Partially free[a]	0.002 (0.086)	-0.022 (0.092)	-0.031 (0.088)	0.025 (0.087)
Civil and political freedom: Not free[a]	-0.029 (0.115)	-0.068 (0.124)	-0.064 (0.118)	0.016 (0.117)
Log population	0.778*** (0.060)	0.645*** (0.062)	0.695*** (0.064)	0.726*** (0.064)
Intercept	-9.012*** (1.036)	-6.335*** (1.051)	-7.494*** (1.099)	-8.267*** (1.109)
Goodness-of-fit statistics				
Wald chi2 test	286.61***	178.38***	192.95***	208.66***
Degrees of freedom	363	363	363	360
ρ	0.961	0.962	0.966	0.968
SSE	9.107	7.702	7.427	7.780
SEE	0.211	0.231	0.220	0.210
$\hat{\sigma}_u$	1.051	1.156	1.176	1.147
θ	0.840	0.841	0.851	0.855
Effect Test	677.38***	677.28***	684.61***	681.25***
N	492	492	492	488

Note. Standard errors in parenthesis.

[a]Indicator.

*p < .05. ** p < .01. *** p <.001.

Panel data analyses also indicated that, compared with their counterpart countries, countries that are designated as followers in technological capability have more outbound STEM students. Lastly, as expected, other variables being equal, countries with large populations are likely to have more outbound STEM enrollment.

The random effects estimation in Model 4 was found to be a good fitting statistical model. Model 5 shows a high value of ρ (0.961), suggesting that the individual specific error can explain 96% of entire composite error variance.

Models 5, 6, and 7 yield similar results as those in Model 4, except for the specific independent variables that were regressed in specific models. Model 5 examined national students' rate of participation in domestic STEM programs and shows a positive relationship with outbound STEM enrollment.

Model 6 specifically examined the proportion of universities ranked in top 500 Academic Ranking of World Universities. The analyses show that other variables being equal, the high proportion of ranked universities is positively associated with the outflow of STEM student.

Model 7 specifically examined science and technology journal articles *per capita*, an informative variable of scientific output, in relation to the outflow of STEM student. The analyses' results indicate that countries with more science and technology journal articles *per capita* exhibit more outbound STEM enrollment.

The random effects estimation in Models 5, 6, and 7 were found to be good fitting statistical models, which have high values of ρ (0.962~0.968), suggesting that the individual specific error can explain over 96% of entire composite error variance.

Bilateral Links Examined in the Push Model

The Push Model in this study further examined the bilateral links (geographic, colonial, linguistic, and social) between a host country and students' home countries in association with student demand for tertiary-level STEM education in Australia, the UK, and the US. The analyses were performed for these three host countries separately. Table 10 summarizes the descriptive statistics regarding bilateral links between a host country and a home country, and the number of students from that home country enrolled in tertiary-level STEM programs in Australia, the UK, or the US. As shown, on average, the number of students from a given country who are enrolled in the US is much larger than that in Australia or the UK.

Regarding bilateral links between a given host country and a home country, 14 out of the 124 countries (11%) share a geographic link (when a home country is located in the same geographic region as a host country) with Australia (East and Southeast Asia, and the Pacific); 92 with the UK (Europe) (74%); and 18 with the US (the Americas) (15%). Moreover, 28 of the 124 countries analyzed (23%) share a linguistic link with the three host countries, as these countries use English as the official language. With respect to colonial links, 1 out of the 124 countries (0.1%) was formally colonized by Australia, 33 by the UK (27%), and 4 by the US (3%). Lastly, regarding social links, among total emigrants from a given home country, on average 3.2% migrate to Australia, 4.6% to the UK, and 16.5% to the US.

Table 10

The Push Model: Descriptive Statistics of Bilateral-link Variables and the Numbers of Students from a Home Country Enrolled in Tertiary-level STEM Programs in Australia, the UK and the US, Years 2006-2009

	N	Mean	Standard Deviation
Number of students from a country enrolled in tertiary-level STEM programs in Australia	492	368.677	1364.992
Geographic link[a] with Australia	496	14[b]	0.317
Linguistic link[a] with Australia	496	28[b]	0.419
Colonial link[a] with Australia	496	1[b]	0.090
Social link	496	3.218	7.781
Number of students from a country enrolled in tertiary-level STEM programs in the UK	492	725.297	1772.812
Geographic link[a] with the UK	496	92[b]	0.438
Linguistic link[a] with the UK	496	28[b]	0.419
Colonial link[a] with the UK	496	33[b]	0.442
Social link with the UK	496	4.587	8.151
Number of students from a country enrolled in tertiary-level STEM programs in the US	492	1364.604	5923.085
Geographic link[a] with the US	496	18[b]	0.353
Linguistic link[a] with the US	496	28[b]	0.419
Colonial link[a] with the US	496	4[b]	0.177
Social link with the US	496	16.479	20.553

Note.[a]Indicator. [b]Number of countries.

Besides the variables of bilateral links, the analyses included variables pertaining to the characteristics of students' home countries (human capital determinants, higher education systems, science and technology intensity, civil and political freedom) as independent variables. The next section presents the analytical results of student demand for STEM education in these three host countries separately, followed by a summary.

Student Demand for STEM Education in Australia: Correlation Analyses.

Table 11 presents correlations among variables in this analysis (Australia as the host country). As shown, all four types of bilateral links (geographic, linguistic, colonial, and social links) have positive and significant relations with the outbound STEM enrollment in Australia. Among independent variables, a geographic link and a social link are positively related, and the relation is statistically significant ($r=.288$, $p<0.001$). Gross national income (GNI) *per capita* is significantly related to the technological capability of students' home countries, and the relation is positive for countries with advanced technological capability ($r=.554$, $p<0.001$), whereas the relation is negative for countries with marginalized technological capability ($r=-.589$, $p<0.001$). To avoid multicollinearity, the independent variables that were correlated were not entered in the same statistical models.

Table 11

Correlation Matrix: International STEM Students in Australia

Variable		Name	1	2	3	4	5	6	7
Dependent	1	Log number of outbound STEM students in the Australia	1.000						
Independent	2	Geographic link[a]	0.498***	1.000					
	3	Linguistic link[a]	0.174	0.051	1.000				
	4	Colonial link[a]	0.096**	-0.032	0.167**	1.000			
	5	Social link	0.222***	0.288***	0.278	0.249	1.000		
	6	Gross national per capita PPP	0.357*	0.059	-0.044	0.113**	0.207	1.000	
	7	Emigration rate of people who have attained higher education	-0.186**	-0.014	0.279***	0.002	0.116*	-0.140**	1.000
	8	Proportion of emigrants who have attained tertiary education	0.521***	0.231***	0.324***	0.047	0.005	0.249***	-0.239***
	9	No doctoral programs[a]	-0.302***	-0.058	0.146**	-0.034	-0.119	-0.199***	0.242***
	10	Technology capability: Advanced[a]	0.245	0.070	0.051	0.219***	0.223	0.554***	-0.150**
	11	Technology capability: Followers[a]	-0.009**	-0.028***	-0.236***	-0.085	0.045	0.184***	-0.106*
	12	Technology capability: Marginalized[b]	-0.164	-0.022**	0.204***	-0.072**	-0.208	-0.589***	0.217***
	13	Civil and political partially free[a]	-0.075	0.024	-0.006	-0.058	-0.102	-0.271***	0.087
	14	Civil and political: not free[a]	0.007	0.072***	-0.100*	-0.048*	-0.128**	-0.160***	-0.142**
Control	15	Log population	0.537***	0.258	0.006	0.094***	-0.125*	-0.144**	-0.294***

Note.[a]Indicator.
*p < .05. ** p < .01. *** p <.001.

Table 11 (Continued)

	Name	8	9	10	11	12	13	14	15
8	Proportion of emigrants who have attained tertiary education	1.000							
9	No doctoral programs[a]	-0.149**	1.000						
10	Technology capability: Advanced[a]	0.244***	-0.156***	1.000					
11	Technology capability: Followers[a]	-0.094*	-0.244***	-0.386***	1.000				
12	Technology capability: Marginalized[b]	-0.080	0.363***	-0.328***	-0.745***	1.000			
13	Civil and political freedom: Partially free[a]	-0.024	0.107*	-0.264***	0.041	0.148***	1.000		
14	Civil and political freedom: Not free[a]	0.010	0.168***	-0.219***	-0.117**	0.278***	-0.339***	1.000	
15	Log population	0.197***	-0.337***	0.071	-0.098*	0.049	-0.022	0.122**	1.000

Note.[a]Indicator.
*$p < .05$. ** $p < .01$. *** $p < .001$.

Panel Data Analyses.

The first step in the modeling process was to perform random-effect estimation based on the assumption that the individual country's heterogeneity was captured in the disturbance term and the individual (group) effect was not correlated with any independent variables (Park, 2011).

Table 12 presents the results of one-way random group effect estimation (Australia as the host country). The results of the Breusch-Pagan Lagrange multiplier (LM) test rejected the null hypothesis and suggested that random effects existed. Additionally, the random effects estimations show that having a geographic link with Australia positively and significantly relates to greater demand for STEM education in Australia and the relation is statistically significant.

According to the panel data analysis, social links matter. High numbers of total emigrants from the same origin who reside in Australia (social links) are associated with more students enrolled in STEM programs in Australia.

Similarly, countries that have higher gross national income (GNI) *per capita* are likely to have more students enrolled in STEM education programs in Australian higher education institutions.

The results of the random effects estimations also indicated that a country's proportion of emigrants to OECD countries who have attained tertiary education was positively related to its outflows of STEM students to Australia. Moreover, within expectation, the log population was found to be positively related to outbound STEM enrollment in Australia.

Table 12

Panel Data Models of Regressions on Log Outbound STEM Enrollment in Australia, Years 2006-2009 (N=488)

Home-country variable	One-way random group effect model
	Model 8
Geographic link[a]	1.985***
	(0.457)
Linguistic link[a]	0.067
	(0.361)
Colonial link[a]	-0.626
	(1.439)
Social link	0.045*
	(0.019)
Gross national income *per capita* purchasing power parity (PPP) (US$1000)	0.038***
	(0.007)
Emigration rate of tertiary-educated people to OECD countries	0.010
	(0.012)
Proportion of emigrants to OECD countries who have attained tertiary education	0.060***
	(0.011)
Unavailability of doctoral programs	-0.003
	(0.182)
Technology capability: Followers[a]	0.108
	(0.259)
Civil and political freedom: Partially free[a]	-0.042
	(0.132)
Civil and political freedom: Not free[a]	0.006
	(0.175)
Log population	0.728***
	(0.086)
Intercept	-11.858***
	(1.502)
Goodness-of-fit statistics	
Wald chi2 test	272.46***
Degrees of freedom	360
ρ	0.947
SEE	0.312
$\hat{\sigma}_u$	1.316
θ	0.826
Effect Test	671.63***
N	488

Note. Standard errors in parenthesis.

[a]Indicator.

p* < .05. ** *p* < .01. * *p* <.001.

Lastly, as there is no generally accepted standard for measures of goodness-of-fit in panel data models (Kunst, 2009), this study uses the ratio of individual specific error variance to the composite error variance (shown as ρ in STATA output tables) as a goodness-of-fit of random effect model (Park, 2011, p. 37). Table 12 shows that this random-effect estimation model has a high value of rho (.947), suggesting that, in this random effects model, the individual specific error can explain around 95% of entire composite error variance.

Student Demand for STEM education in the UK: Correlation Analyses

Table 13 presents correlations among variables in this analysis (UK as the host country). The results show that three types of bilateral links (linguistic, colonial, and social links) are positively related to student demand for STEM education in the UK, and the relations are statistically significant.

Among independent variables, the correlation matrix shows that three bilateral links are correlated — colonial, linguistic, and social links. Their relations are positive and significant, which suggest that: (a) countries that were formally colonized by the UK tend to have English as their official language, (b) countries that use English as the official language tend to have higher proportion of emigrants to the UK, and (c) countries that were formally colonized by the UK tend to have a higher proportion of emigrants that reside in the UK.

Additionally, the correlation analyses show that gross national income *per capita* is positively associated with a country's status as technologically advanced and negatively associated with its status as technologically marginalized. To avoid multicollinearity, the independent variables that were correlated were not entered in the same statistical models.

Table 13

Correlation Matrix: International STEM Students in the UK

Variable		Name	1	2	3	4	5	6	7
Dependent	1	Log number of outbound STEM students in the UK	1.000						
Independent	2	Geographic link[a]	-0.005***	1.000					
	3	Linguistic link[a]	0.183	-0.078	1.000				
	4	Colonial link[a]	0.338**	-0.020	0.722**	1.000			
	5	Social link	0.397***	0.054***	0.519	0.568	1.000		
	6	Gross national per capita PPP	0.523*	0.025	-0.044	0.159**	0.243	1.000	
	7	Emigration rate of people who have attained higher education	-0.110*	-0.126**	0.265***	0.186***	0.180***	-0.140**	1.000
	8	Proportion of emigrants who have attained tertiary education	0.401***	-0.033	0.337***	0.427***	0.293***	0.249***	-0.239***
	9	No doctoral programs[a]	-0.406***	0.000	0.146**	0.159	-0.068	-0.199***	0.242***
	10	Technology capability: Advanced[a]	0.274	-0.019	0.051	0.011***	0.090	0.554***	-0.150**
	11	Technology capability: Followers[a]	0.158**	-0.112***	-0.236***	-0.089	-0.006	0.184***	-0.106*
	12	Technology capability: Marginalized[b]	-0.356	0.128**	0.204***	0.083**	-0.059	-0.589***	0.217***
	13	Civil and political freedom: Partially free[a]	-0.193	-0.059	-0.006	0.067	-0.054	-0.271***	0.087
	14	Civil and political freedom: Not free[a]	-0.087	0.124***	-0.100*	-0.055*	-0.153**	-0.160***	-0.142**
Control	15	Log population	0.434***	-0.247	-0.006	-0.087***	-0.119*	-0.144**	-0.294***

Note. [a]Indicator.
*$p < .05$. ** $p < .01$. *** $p < .001$.

Table 13 (Continued)

	Name	8	9	10	11	12	13	14	15
8	Proportion of emigrants who have attained tertiary education	1.000							
9	No doctoral programs[a]	-0.149**	1.000						
10	Technology capability: Advanced[a]	0.244***	-0.156***	1.000					
11	Technology capability: Followers[a]	-0.094*	-0.244***	-0.386***	1.000				
12	Technology capability: Marginalized[b]	-0.080	0.363***	-0.328***	-0.745***	1.000			
13	Civil and political freedom: Partially free[a]	-0.024	0.107*	-0.264***	0.041	0.148***	1.000		
14	Civil and political freedom: Not free[a]	0.010	0.168***	-0.219***	-0.117**	0.278***	-0.339***	1.000	
15	Log population	0.197***	-0.337***	0.071	-0.098*	0.049	-0.022	0.122**	1.000

Note. [a]Indicator.
p* < .05. ** *p* < .01. * *p* <.001.

Panel Data Analyses

Table 14 presents the results of one-way random group effect estimation (UK as the host country). All these three models have the same dependent variable (log number of students from a given home country who are enrolled in STEM education in U.K. higher education institutions). All these three models also have nearly the same set of independent variables, except for three correlated variables—linguistic links, colonial links, and social links.

The results of this analysis show that all four bilateral links are associated with the flows of STEM students. Possessing a geographic link to the UK significantly relates to a greater demand for STEM education in the UK.

Possessing a linguistic link was found to be positively related to student demand for STEM education in the UK at the .05 significance level. Similarly, having a colonial link with the UK also has a positive association.

Sharing social links was found to be a significant factor in student mobility. Higher percentages of emigrants from the same origin who reside in the UK (social links) are associated with higher enrollment in STEM programs in the UK.

The results of random effects estimations also indicate that countries that have higher gross national income (GNI) *per capita* are likely to have more students enrolled in STEM education programs in U.K. higher education institutions.

Countries that are followers in technological capability tend to have more students enrolled in STEM programs in the UK compared with their counterpart countries.

Table 14

The Push Model: Panel Data Models of Regressions on Log Outbound STEM Enrollment in the UK (N = 488), Years 2006-2009

	One-way random group effect model		
	Model 9	Model 10	Model 11
Geographic link[a]	1.050***	1.003***	0.886**
	(0.277)	(0.260)	(0.266)
Linguistic link[a]	0.831**		
	(0.317)		
Colonial link[a]		1.300***	
		(0.284)	
Social link			0.077***
			(0.015)
Gross national income *per capita* purchasing power parity (PPP) (US$1000)	0.067***	0.064***	0.061***
	(0.007)	(0.007)	(0.007)
Emigration rate of tertiary-educated people to OECD countries	0.035**	0.031**	0.030**
	(0.011)	(0.010)	(0.011)
Proportion of emigrants to OECD countries who have attained tertiary education	0.033**	0.022*	0.028**
	(0.010)	(0.010)	(0.009)
Unavailability of doctoral programs[a]	-0.034	-0.118	0.021
	(0.203)	(0.202)	(0.199)
Technology capability: Followers[a]	0.985***	0.887***	0.840***
	(0.244)	(0.226)	(0.230)
Civil and political freedom: Partially free[a]	-0.078	-0.150	-0.068
	(0.147)	(0.145)	(0.144)
Civil and political freedom: Not free[a]	-0.066	-0.148	0.040
	(0.192)	(0.187)	(0.187)
Log population	0.818***	0.842***	0.838***
	(0.080)	(0.076)	(0.077)
Intercept	-12.494***	-12.460***	-12.482***
	(1.485)	(1.400)	(1.421)
Goodness-of-fit statistics			
Wald chi2 test	259.95***	309.88***	305.26***
Degrees of freedom	360	360	360
ρ	0.917	0.905	0.911
SEE	0.369	0.373	0.363
$\hat{\sigma}_u$	1.223	1.151	1.161
θ	0.796	0.781	0.788
Effect Test	618.190***	599.290***	611.210***
N	488	488	488

Note. Standard errors in parenthesis.

[a]Indicator.

p* < .05. ** *p* < .01. * *p* <.001.

The results show that a home country's emigration rate of people that have attained tertiary education is positively related to demand for STEM education in the UK.

The results of random effects estimations also reveal that the proportion of emigrants to OECD countries that have attained tertiary education is positively related to demand for STEM education in the UK. Additionally, as expected, a country's population was found to be positively related to outbound STEM enrollment in the UK.

The results of panel data analyses show that Model 9 has slightly higher rho of 0.917, which suggests that the individual specific error can explain 91.7% of the entire composite error variance. All three models have a high value of rho over 0.90, implying that all of these statistical models have good explanatory power.

Student Demand for STEM Education in the US: Correlation Analyses.

Table 15 presents correlations among variables in this analysis (US as the host country). As shown, three types of bilateral links (geographic, colonial, and social links) have positive and significant relations with the dependent variable: outbound STEM enrollment in the US. Among independent variables, geographic links and social links are positively and significantly related ($r=0.637$, $p<.001$). Gross national income (GNI) *per capita* is significantly related to the technological capability of students' home countries. To avoid multicollinearity, these independent variables that were correlated were not entered in the same statistical models.

Table 15

Correlation Matrix: International STEM Students in the US

Variable		Name	1	2	3	4	5	6	7
Dependent	1	Log number of outbound STEM students in the US	1.000						
Independent	2	Geographic link[a]	0.152***	1.000					
	3	Linguistic link[a]	0.054	-0.058	1.000				
	4	Colonial link[a]	0.126**	-0.075	0.120**	1.000			
	5	Social link	0.275***	0.637***	0.013	0.036	1.000		
	6	Gross national per capita PPP	0.097*	-0.084	-0.057	0.118**	0.006	1.000	
	7	Emigration rate of people who have attained higher education	-0.128**	0.169***	0.283***	-0.073	0.260***	-0.140**	1.000
	8	Proportion of emigrants who have attained tertiary education	0.306***	-0.167***	0.321***	0.080	-0.132**	0.249***	-0.239***
	9	No doctoral programs[a]	-0.397***	0.052	0.146**	-0.069	0.050	-0.199***	0.242***
	10	Technology capability: Advanced[a]	0.072	-0.040	0.051	0.184***	0.072	0.554***	-0.150***
	11	Technology capability: Followers[a]	0.131**	0.164***	-0.236***	0.012	0.013	0.184***	-0.106*
	12	Technology capability: Marginalized[b]	-0.185	-0.140**	0.204***	-0.145**	-0.066	-0.589***	0.217***
	13	Civil and political freedom: Partially free[a]	0.007	0.052	-0.006	-0.041	-0.069	-0.271***	0.087
	14	Civil and political freedom: Not free[a]	-0.007	-0.219***	-0.100*	-0.097*	-0.144**	-0.160***	-0.142**
Control	15	Log population	0.699***	0.075	-0.025	0.193***	0.094*	-0.144**	-0.294***

Note. [a]Purchasing Power Parity. [b]Indicator.
p* < .05. ** *p* < .01. * *p* <.001.

Table 15 (Continued)

Correlation Matrix: International STEM Students in the US

	Name	8	9	10	11	12	13	14	15
8	Proportion of emigrants who have attained tertiary education	1.000							
9	No doctoral programs[a]	-0.149***	1.000						
10	Technology capability: Advanced[a]	0.244***	-0.156***	1.000					
11	Technology capability: Followers[a]	-0.094*	-0.244***	-0.386***	1.000				
12	Technology capability: Marginalized[b]	-0.080	0.363***	-0.328***	-0.745***	1.000			
13	Civil and political freedom: Partially free[a]	-0.024	0.107*	-0.264***	0.041	0.148***	1.000		
14	Civil and political freedom: Not free[a]	0.010	0.168***	-0.219***	-0.117**	0.278***	-0.339***	1.000	
15	Log population	0.197***	-0.337***	0.071	-0.098*	0.049	-0.022	0.122**	1.000

Note. [a]Purchasing Power Parity. [b]Indicator.
p* < .05. ** *p* < .01. * *p* <.001.

Panel Data Analyses.

Table 16 presents the results of one-way random group effect estimation (US as the host country). Model 12 and Model 13 have the same dependent variable (log number of students from a given home country enrolled in STEM programs in U.S. higher education institutions). These two models differ in using two correlated bilateral link variables (geographic links and social links) separately.

The results from panel data analyses show that both geographic links and social links are related to student demand for STEM education in the US. The statistical significance level of these two variables is different, with social links appearing to have a greater level of significance.

The results found in Model 12 and Model 13 show that national wealth (gross national income *per capita*) is positively related to the outflows of STEM student to the US. Moreover, the results show that countries that are followers in technological capability tend to have more outflows of students enrolled in STEM programs in the US when compared with their counterpart countries.

The results of random effects estimations indicate that the proportion of emigrants (to OECD countries) that have attained tertiary education was positively related to demand for STEM education in the US. Additionally, as expected, log population was found to be positively related to outbound STEM enrollment in the US.

Finally, both these two random effects estimations have a high value of ρ (over .930), suggesting that in these models, the individual specific error can explain over 93.0% of the entire composite error variance.

Table 16

Panel Data Models of Regressions on Log Outbound STEM Enrollment in the US (N=488), Years 2006-2009

	One-way random group effect model	
	Model 12	Model 13
Geographic link[a]	0.751*	
	(0.338)	
Linguistic link[a]	0.102	0.145
	(0.307)	(0.296)
Colonial link[a]	-0.427	-0.566
	(0.638)	(0.613)
Social link		0.020***
		(0.005)
Gross national income *per capita* purchasing power parity (PPP) (US$1000)	0.019**	0.017*
	(0.006)	(0.006)
Emigration rate of tertiary-educated people to OECD countries	0.022*	0.016
	(0.011)	(0.011)
Proportion of emigrants to OECD countries who have attained tertiary education	0.033**	0.031***
	(0.010)	(0.010)
Unavailability of doctoral programs[a]	0.065	0.043
	(0.167)	(0.166)
Technology capability: Followers[a]	0.726**	0.814***
	(0.236)	(0.222)
Civil and political freedom: Partially free[a]	0.089	0.115
	(0.122)	(0.121)
Civil and political freedom: Not free[a]	0.032	0.052
	(0.162)	(0.161)
Log population	0.927***	0.892***
	(0.075)	(0.074)
Intercept	-11.988***	-11.591***
	(1.293)	(1.258)
Goodness-of-fit statistics		
Wald chi2 test	218.65***	244.66***
Degrees of freedom	360	360
ρ	0.943	0.938
SEE	0.294	0.296
$\hat{\sigma}_u$	1.195	1.155
θ	0.825	0.818
Effect Test	651.090***	645.360***
N	488	488

Note. Standard errors in parenthesis.

[a]Indicator.

*p < .05. ** p < .01. *** p <.001.

CHAPTER FIVE

DISCUSSION AND CONCLUSION

Summary of Findings

Three research questions have been investigated in this study: (a) what are the emerging trends in the cross-border mobility of international STEM students? (b) How are host-countries' characteristics related to their attractiveness to international STEM students (or their international STEM enrollment)? (c) How are the characteristics of students' home countries related to student demand for tertiary-level STEM education in Australia, the UK, and the US? The following provides a discussion of this study's findings.

Emerging Trends in the Mobility of International STEM Students

The trend analyses reveal at least four emerging trends in the cross-border mobility of international STEM students. First, international STEM enrollment in the Organisation for Economic Co-operation and Development (OECD) countries increased by a factor of 1.4 between 2004 and 2010. Also, the growth rate of this population (international STEM enrollment in OECD countries) is greater than that of national STEM enrollment in these countries. On the one hand, this trend implies that international students' demand for STEM education in OECD countries has increased; on the other, it suggests that OECD countries expand their supply of STEM education to international students.

Second, international STEM students are increasingly concentrated in English-speaking countries. This indicates that the use of English for instruction in higher education institutions attracts international STEM students. Third, international STEM students are increasingly enrolled in host countries with advanced technological capabilities.

The fourth emerging trend is that, in students’ home countries, the capacity of higher education systems to supply STEM education has increased substantially, perhaps meeting local students’ need for STEM education and, in turn, slowing the outflow of students. The results of trend analyses in the study show that in students’ home countries, the growth rate of enrollments in domestic tertiary-level STEM programs is greater than that of the outflows of STEM students to Australia, the UK, and the US (Figure 12). This trend (the growth of domestic STEM enrollment) also indicates that the local and international growth of STEM enrollments corresponds to the projected increased demand for scientists and engineers worldwide, which will likely stimulate more students to major in STEM fields (Galama & Hosek, 2009).

Pull Model: Host-Country Characteristics and International Student Enrollment

Using random effects estimations, this study identified five host-country characteristics that have a significant relationship to international STEM enrollment, including (a) English-language instruction, (b) national students’ rate of participation in STEM programs, (c) the proportion of universities ranked in top 500 Academic Ranking of World Universities, (d) total enrollment of a higher education system, (e) advanced technological capability, and (f) aging population.

The first significant characteristic, the use of English in science and scholarship, could explain why students in scientific and technological disciplines are more likely to study in countries with programs offered in English. Universities are international institutions, and so the language of science and scholarship plays a central role in creating openness to faculty and student flows and borderless knowledge creation and dissemination (Altbach, 2011). By the beginning of the 21st century, English had emerged as the nearly universal medium of scientific communication (Altbach, 2011; Lillis & Curry, 2010). The recent development shows top tier international journals use English language, and scientific databases also use English as the medium for communication. In non-English speaking countries, universities use English for instruction in certain disciplines. English as a language of science and scholarship motivates international STEM students to choose studying in countries (or institutions) with programs offered in English or in English-speaking countries.

Another characteristic, national students' rate of participation in OECD countries, was found to have a negative relationship with international STEM enrollment. It is likely that, when more national students are enrolled in domestic STEM programs, fewer seats are left for students from abroad. Conversely, when national STEM enrollment decreases, universities may enroll more international students to fill the seats left by national students. This finding is consistent with statements in previous studies (e.g., de Wit, 2008a). Now, with this study, the negative relationship between national and international STEM enrollment is empirically confirmed.

Another characteristic, the proportion of universities ranked in top 500 Academic Ranking of World Universities, was found to have positive relationship with international student enrollment.

The total enrollment of a higher education system (the control variable was found to be significantly and positively related to international STEM enrollment. This finding is consistent with existing studies (e.g., Cummings, 1993; Rosenzweig, 2008). Generally, a larger higher education system, other variables being equal, has a greater capacity to accommodate more students.

The fourth characteristic identified in this study as important to international STEM enrollments is a country's technological capability. Countries with advanced technological capability enroll more international STEM students than their counterpart countries (designated as followers in technological capability). Countries with advanced technological capability appeal to international STEM students because these countries generally have universities with well-equipped labs, cutting-age scientific knowledge, high academic qualifications for university instructors, and better research funding, all of which are appealing to international STEM students (Altbach, Kelley, & Lulat, 1985; Castellacci & Archibugi, 2008; Hazelkorn, 2009; OECD, 2008b).

This study indicates that demographics (specifically the statistically significant and positive relation between countries' aging population and the inflow of international STEM students) may provide insight into the emerging patterns of international higher education. Countries with a high proportion of aging citizens face the threat of insufficient numbers of young citizens to support their societies or economies in the long run; the constant demand for a steady supply of health care workers constitutes one such crucial factor (de Wit, 2008a). In order to meet the call for more science and technology human resources, those countries often relax immigration policies and welcome international students in STEM fields to stay and work after graduation. As is made clear in national and international agencies' reports and scholarly papers (e.g., de Wit, 2008a; Galama & Hosek, 2009), Europe's demographic changes predict a shortage of students, especially in sciences and health fields, that translates to a strong trend among European countries to recruit students from abroad and particularly from developing countries.

Push Model: The Characteristics of Students' Home Countries and the Outflow of STEM Students

The results of random-effects estimations also indicated that seven characteristics of students' home countries are significant variables related to the outflow of students: (a) national income *per capita* PPP (as a measure of funding for stud abroad), (b) national technological capability, (c) national students' participation rate in STEM programs, (d) academic reputation of higher education , (e) number of scientific and technological articles *per capita* (as a measure of science and technology intensity), (f) emigration of highly educated people, and (g) proportion of emigrants that have attained tertiary education (f and g as measures of expected benefits of studying abroad).

According to this study's analyses, students from countries designated as followers in technological capability are more likely to leave their home countries to study STEM education in Australia, the UK, and the US, compared with their counterparts in countries with advanced technological capability or in countries with marginalized technological capability. According to Castellacci and Archibugi (2008), countries designated as followers in technological capability have a much lower ability (compared to the advanced cluster) to create and imitate advanced knowledge. In order to enhance their innovative capability, which usually requires more higher-education graduates in STEM fields, it is plausible that national governments in these countries provide financial support to send their students to study STEM education in technologically advanced countries. It is also possible that students from these follower countries may view STEM education in Australia, the UK, and the US as an extension of educational opportunities that may redound to the home country. In contrast, in countries with advanced technological capability, students may be less motivated than students from countries designated as followers to migrate to other countries when abundant resources and quality higher education are available within their countries.

The analyses also revealed that countries with marginalized technological capabilities exhibit the lowest outflows of students to pursue STEM education in Australia, the UK, and the US. Castellacci and Archibugi (2008) observed that over the decade between 1990 and 2000, though this cluster of countries improved in terms of Internet and phone service, only minor progress was made in other aspects of technological infrastructure and human skills (i.e., electricity consumption, science and engineering enrollment ratio, years of schooling, and literacy rate), let alone innovative capability, which requires solid technological infrastructure and human skills. Few students receive science and technology education in these countries' schools, so there are few qualified candidates for admittance to universities abroad. The correlation (low domestic STEM enrollment resulting in fewer STEM graduates, and fewer qualified candidates for higher levels of STEM educational programs) also lends support for another related characteristic of students' home countries—national students' participation in STEM education.

The random effects estimations performed in this study also indicate that countries where the participation rate of national students in domestic tertiary-level STEM programs is low are likely to exhibit low demand for overseas STEM education. Low domestic STEM enrollment can imply a limit supply of STEM education in the home country, which may then result in an insufficient number of students prepared for higher-level STEM education. Low domestic STEM enrollment can also imply national students' low interest in studying science and technology subjects. In either case—lack of preparation for higher-level STEM education or low interest in STEM education—student demand for overseas STEM education is low.

The results for the two independent variables associated with the emigration of highly educated citizens to OECD countries were in line with expectations. Counties that have a large extent of highly educated citizens immigrating to OECD countries exhibit larger outflows of STEM students to Australia, the UK, or the US. It is important to note that the emigration rate of highly educated citizens to OECD countries is far from the best proxy for understanding the tendency of international STEM students to immigrate to their host countries. Despite the imperfection in measurement, however, the finding reveals that countries that have large outflows of STEM students to Australia, the UK, and the US also have a high emigration rate of their highly educated citizens to OECD countries. It is possible that highly educated citizens of these countries generally tend to search for jobs at better pay and higher quality of life outside their homeland, and that the STEM students in these countries follow suit. Once these students obtain overseas higher education degrees, they may seize opportunities to immigrate to their host countries. Rosenzweig's (2008) and Tremblay's (2005) studies have indicated the tendency of international students immigrating to the host country.

With respect to how bilateral links between the home and the host countries relate to the mobility of international STEM students, this study's analyses show that though colonial links continue to be influential in student mobility, other links have become more dominant. Across student flows to Australia, the UK, and the US, the study found that geographic links and social links play a significant role in directing the flows of international STEM students. International STEM students are likely to choose to study in a country located in their own region, possibly for the sake of reducing travelling cost or enjoying cultural approximation or familiarity in the host country. Another explanation of the inter-regional mobility is the trend toward regionalization. Regionalization is a response to the competitive pressure of the global economy, when nation-states in the same geographic region emphasize regional integration and the development of their own region (Altbach, Reisberg & Rumbley, 2009; Shields, 2013a). Both the creation of the European Higher Education Area and the Association of South East Asian Nations exemplify the regionalization of higher education: both associations initiated credit transfer systems within their respective regions, which allow students to study abroad and gain credits for their study. These types of measures enable students to stay in another country in their own region.

The analyses in this study also show that STEM students gravitate towards countries that have more pre-existing migrants from the same home country (i.e., social links), and this finding is consistent with existing studies (e.g., Perkins, & Neumayer, 2011).

Regarding colonial links and linguistic links, countries that are former colonies of the UK or have English as their official language were found to have more STEM students enrolled in British higher education institutions. However, these two variables are unrelated to student flows to Australia or the US.

Implications for Theory

Three theoretical conceptualizations (human capital theory, neoliberalism, and world-systems analysis) frame this study's focus of inquiry and support its conceptual framework. These perspectives are re-introduced briefly and the findings are incorporated into the discussion below to provide a better understanding of the patterns in the cross-border mobility of international STEM students and of the relation between country characteristics and the mobility of these students.

Human capital theory holds that investment in education (whether by national governments, enterprises, or individuals), as a form of human capital, can yield economic return to individuals and fuel national economic growth (Becker, 1975; 2002; Mincer, 1958; Schultz, 1961). In particular, the global reach of knowledge economy discourses means that higher education institutions are expected to supply more graduates of specialized technological knowledge and skills to economies or societies (Altbach, Reisberg & Rumbley, 2009; Shields, 2013a). The analyses conducted in this study provide evidence that STEM enrollment at the tertiary level in the 124 countries analyzed has increased significantly.

From the perspective of human capital theory, student demand for overseas education is expected to vary in accordance with educational opportunities in the home country, financial resources, costs of studying abroad, and expected benefits attributable to studying abroad (Argarwal & Winkler, 1985; Lee & Tan, 1984; Rosenberg, 2008). In this regard, the study's findings support human capital theory's precepts. First, the random effects estimations show that, proportionally, more students from wealthier countries than from poorer countries pursue an overseas higher education degree in STEM fields. Second, two indicators examined in this study suggest that studying abroad offers students potential (permanent or temporary) immigration opportunities, which may influence demand for overseas STEM education. These two indicators are: (a) the high percentage of international students who change their student status and stay on in the host country (ranging from 17% to 33% as shown in Table 4.2), and (b) the positive and statistically significant relationship between the outflow of STEM students and the emigration rate of highly educated citizens.

Neoliberal theory attributes the globalization of higher education to increased global competition through initiatives such as free markets, deregulation, enhanced privatization, and an overall reduction in government control (Shields, 2013a). Neoliberalism views the mobility of international STEM student as a result of increased competition among higher education institutions and among countries (Hazelkorn, 2009; Shields, 2013b). Universities and countries adopt practices that are more efficient to recruit international students. As a result, as reported by UNESCO (UNESCO-UIS, 2009), a number of countries other than traditionally popular destinations for international students have emerged as destinations for studying abroad, such as China, Malaysia, Singapore, and South Africa.

Although the stiff competition indicated by neoliberal theory may be expected to lead to more dispersed international enrollment across traditionally popular destination countries and emerging ones (Shields, 2013b), the analyses in this study show that international STEM students are concentrated in a few English-speaking, technologically advanced countries. This finding suggests that some distinction should be made between the mobility of international students in all disciplines and those in STEM fields specifically. The mobility of international STEM students is influenced by additional aspects: for instance, a host country's quality of infrastructure, innovative capability, or research intensity.

World-systems analysis explains that countries and institutions that maintain the resources and knowledge desired by others remain at the center of the world system, whereas countries and institutions with a limited educational capacity to provide quality education stay at the periphery (Chen & Barnett, 2000). In the view of world-systems analysis, students in peripheral countries move to the central countries to access the modern knowledge system. The revolution of information technology and the use of English as the language of science and scholarship in the 21st century (Altbach, 2011;

Lillis & Curry, 2010) have further stabilized the central position of countries that are advanced in high technology (Altbach, 2006). This view is supported by this study’s findings: according to its analyses, countries that offer English-instruction programs or that possess advanced technological capabilities enroll more international STEM students than their counterpart countries.

With respect to the outflows of STEM students, however, world-systems analysis is insufficient to explain why students from technologically marginalized countries are less likely to study STEM education abroad and why there is a large outflow of STEM students from technologically advanced countries. According to world-systems analysis, students generally move from peripheral countries (that is, countries designated as technological followers or as technologically marginalized) to advanced countries (that is, countries designated as technologically advanced). The analyses indicate that the outflow of students from technologically marginalized countries is low. It is plausible that the globalization of higher education has erected new barriers in technologically marginalized countries that dissuade engagement in the international network of science (Altbach, 2004) and disable students from technologically marginalized countries from pursuing STEM education abroad. As addressed immediately above, the most prestigious institutions in the world’s wealthiest countries have a disproportionate influence over the development of international standards for scholarship, which leaves poor and technologically marginalized countries at a distinct disadvantage (Altbach, 2004; Altbach, Reisberg & Rumbley, 2009). Countries in the latter cluster have limited financial and human resources for training new generations of scientists and researchers, and they also have few students qualified for admittance by universities in technologically advanced countries.

World-systems analysis also fails to explain why there is a large outflow of STEM students from technologically advanced countries, as shown in the analyses. It is plausible that internationally scientific cooperation, which is a new trend in the globalization of higher education, is valued and that students are encouraged to study abroad to acquire cross-cultural competencies (Altbach, Reisberg & Rumbley, 2009; OECD, 2008b). For instance, in Europe, the mobility of students, early stage researchers, and staff in higher education is the priority of the policy agenda of European Higher Education Area (EHEA) and European Research Area (de Wit, 2008b). The ministers of education in the signatory countries of the Bologna Declaration, for example, work together to achieve an agreed-upon aim that by 2020, at least 20% of EHEA graduates should have a study or training period abroad (EHEA, 2012). In this regard, the mobility of students is not merely a function of underdevelopment; in the case of European Higher Education Area, such mobility is also a mechanism toward regionalization (or Europeanization).

Implications for Policy or Practice

The study’s findings of significant country characteristics for the mobility of international STEM students have implications for higher education policies and practices at the national and institutional levels. The key issues include: (a) human resources in science and technology necessary for participation in the global scientific network, (b) migration of STEM students and workers, and (c) English as the language of science and scholarships.

The global knowledge economy discourse presumes that the supply of human resources in science and technology (whether trained locally or abroad) is critical to economies at all development levels. Critics however argue that the concept of knowledge economy and the assumptions that underpin it are deeply problematic (Robertson, 2005; Shields, 2013a, p. 88). If the presumption of this key issue (i.e., global knowledge economy) holds, this study's findings pose a concern about a widening disparity in technological capability between countries designated as marginalized and their counterpart countries (designated as followers or as technologically advanced). The analyses indicate that the outbound mobility is more prevalent among STEM students from countries designated as technologically advanced and as followers, compared to that of students from countries designated as marginalized. According to Castellacci and Archibugi (2008), follower countries showed very minor improvement in innovative capability between 1990 and 2000. The outward migration of their STEM students to technologically advanced countries (which feature high infrastructure, skills, and innovation) could enhance innovative capabilities in the home country through "brain circulation" (OECD, 2008b). Brain circulation facilitates knowledge diffusion through returning migrants and the network maintained by migrants with their host countries, both of which may counter the negative effects of the loss of highly skilled workers to other economies (OECD, 2008b). Further, technologically advanced countries, as receiving countries of highly skilled students and workers, can also benefit from knowledge flows, increased R&D and creativity, and collaboration with immigrants' home countries (Guellec & Cervantes, 2002; OECD, 2008b).

At the other end of the spectrum, technologically marginalized countries have low domestic STEM enrollment and few students studying STEM education in technologically advanced countries, resulting in a low supply of human resources in science and technology. This raises a concern that technologically marginalized countries are possibly disconnected from the international network of science and technology. To benefit from scientific discovery and technology innovation abroad, these countries need to ensure that there are human skills available domestically to adapt and transform advanced knowledge and technology. To do this, higher education policies in technologically marginalized countries must take into account the causes and impacts of low STEM enrollment and the need for human resources in science and technology.

The second key issue with policy implications is related to the migration of STEM students and workers. The analyses show that STEM students migrate more often from countries that already have higher emigration rates of highly educated citizens. In addition to the concern about brain drain, this presents a worry that in these emigrants' home countries, public infrastructure investment may be adjusted downward (Grossmann & Stadelmann, 2008). Grossmann and Stadelmann (2008) examined how public infrastructure investment responds to the emigration of highly skilled workers in 77 countries. They found that higher outward migration of highly skilled workers is associated with a downward adjustment of public infrastructure investment, which in turn affects income and welfare of non-migrants in the home country. To minimize the negative impacts on non-migrants in the home country, higher education policies may consider initiatives (e.g., international scientific collaboration) that allow the home country to benefit from highly skilled migrants.

The migration of STEM students and workers also has policy implications for receiving countries that face aging populations and low national STEM enrollments. Although these countries may recruit more international STEM students and workers to fill the gaps in the supply of science and technology human resources, it is risky for these countries to rely extensively on international migrants (OECD, 2008b). Countries generally compete for talents from the same pool and also face uncertainties (e.g., migrants may return to home countries when home economies improve), so the supply of international skilled migrants may be unstable. In order to have endogenous human resources in science and technology, higher education policies therefore need to understand factors that lead to low national STEM enrollment and propose measures to counter the trend.

The third key issue that has implications for practice is the use of the English language in STEM educational programs. The finding that English instruction appeals to international STEM students suggests that if institutions in host countries increase the use of English as the instruction language, international STEM students may be more likely to remain there. Universities that aspire to recruit more international STEM students may increase courses taught in English. In fact and in relation to this study’s findings, in some non-English speaking countries, universities have begun to recruit visiting scholars from abroad to offer instruction and training in English, and some have begun to require their own faculty members to teach in English. This practice is becoming more common in science and engineering programs in German and Japanese universities (Altbach, Reisberg & Rumbley, 2009; OECD, 2012).

Limitations

This study has certain limitations that should be considered. One group of limitations relates to sample sizes, and the other group relates to the omission of potential variables. First, the analyses in the Pull Model (enrolling international STEM students) were based on a small sample size (n = 23), which was confined to countries in the Organisation for Economic Co-operation and Development (OECD), most members of which are high-income and are regarded as developed countries. Expanding the population to include countries that emerge as popular host countries for international STEM students (such as China, Malaysia, the Republic of Korea, and Singapore) would add to this study's findings.

Another sample-related limitation was the selection process for countries to be analyzed in the Push Model (students pursuing STEM education abroad). The 124 countries analyzed in the statistical models were not completely randomly selected. In most cases, countries that were excluded from analyses in the Push Model had many missing data points for core variables investigated in this study. Countries with missing data points in international datasets tend to be countries in which the national statistical information systems are weak or absent. In terms of geographic representation, few countries in Latin America and in sub-Saharan Africa were analysed in this study, because of missing data. Thus, the analytical results cannot be generalized to 200 countries worldwide.

With respect to potential variables that are omitted, though this study elaborated the importance of investigating the stay rate of international students, this study did not thoroughly examine this variable due to the sporadic availability of data. Such data were only available for a few countries. Instead, the emigration rate of highly educated citizens was examined as a proxy for the potential benefit of studying abroad. This rate may be influenced by the relaxation of immigration policies on the part of some countries. In addition, this study did not examine financial variables, such as tuition and fees, and scholarships and assistantships for international students, which may influence international STEM students’ choices of where to study. It would be helpful to understand how the stay rate of international students and financial support for these students contribute to international STEM enrollment.

Another limitation is this study’s lack of consideration of within-country heterogeneity. For instance, within the same country, individual institutions have varied capacities to enroll international students, and differences in wealth between the rich and the poor affect students’ opportunities to study abroad. Such heterogeneity is not reflected in the secondary data and country-level administrative data used in this study. Kaiser and O’Heron’s (2005) comment pointed out the challenge of using secondary data: “problems with the availability of relevant data and large differences in institutional setting have made it difficult over the years to identify, calculate and use appropriate indicators" (p. 39). This limitation is common, as secondary data can rarely completely fulfill the data requirement needed for studies.

In spite of its limitations, this study design offers several significant findings and suggests meaningful directions for further work.

Directions for Future Research

This study's findings contribute to the ongoing research concerning host countries' ability to recruit and enroll international STEM students, the outflows of STEM students from both developed and developing countries, and issues related to brain drains, brain circulations, and brain gains. It therefore offers a wealth of opportunity for future research focused on the cross-border movement of international students in STEM fields.

There are a number of potential factors worth investigating to understand further the cross-border flows of international STEM students. The variables for future research include the stay rate of international students, economic factors, such as bilateral trades and the unemployment rates in host and home countries, and factors related to immigration policies. In the future, researchers can include these variables in their studies and thereby potentially increase statistical significance of research results.

Additionally, future research can take a different methodological approach by surveying individual international students or individual universities (in contrast to conducting a national-level study). Finally, future studies may analyze international STEM students who study in non-English speaking countries such as France, Germany, and Japan,among the top six host countries for international STEM students.

Conclusion

This study has considered the mobility of a neglected sub-group of international students: international students in science, technology, engineering, and mathematics (STEM) fields. The analyses have shown that the mobility of international STEM students is influenced by a combination of pull and push factors (de Wit, 2008a; Cummings, 1993; Hazelkorn, 2009). International STEM students are increasingly attracted by and are polarized in English-speaking countries and in countries with advanced technological capability. This finding lends support to world-systems analysis, which suggests that the polarization of international student flows reflects global economic interests and relationships of power and hegemony (Shields, 2013b, p.630).

At the same time, changes in demographics are in play: an aging population and a decline in national students enrolled in STEM programs in OECD countries motivate these countries to proactively recruit students from abroad to fill the gaps of the production of science and technology human resources and sustain technological competiveness. These countries not only enroll international STEM students but also often welcome highly skilled international STEM students to stay after graduation. One approach that several countries have taken is to relax immigration policies favoring international students in STEM fields who obtain a higher education degree. This approach seems to be working, and it also works for students who strategically use study abroad as a precursor to immigrate to countries with better-paid jobs (Rosenzweig, 2008; Trambaly, 2005).

The outflow of STEM students is evident and significant in countries where the emigration rate of highly educated citizens to OECD countries is high. Though this study does not provide direct evidence about the proportion of international STEM students who immigrate to OECD countries, the positive relationship indicates that these countries have large emigration rates of highly educated citizens and large outflows of STEM students, which raises concerns in ongoing debates about brain drains. This study’s trend analyses show however that the outflow of STEM students responds to the enhancement in domestic higher education systems to supply STEM education, which could meet local students’ need for STEM education and, in turn, slow the outflow of students.

There is a widening disparity in scientific and technological capabilities between economies. This study’s analyses reveal that a large outflow of STEM students come from countries designated as followers or those designated as advanced in technological capabilities, and particularly from the former cluster. By contrast, a low outflow from countries with marginalized technological capability is evident. Technologically marginalized countries, on the one hand, are not able to offer sufficient domestic science and technology education, which in turn, results in a limited supply of technological human skills to economies. On the other hand, these countries also have low number of students pursuing STEM education in technologically advanced countries, such as Australia, the UK, and the US, which might lead to further disconnection from the international network of scientific and technological knowledge. Higher education policies in countries with marginalized technological capability cannot be appropriate formulated without pay attention to producing higher education graduates in STEM fields (schooling locally or abroad) to ensure that there are human skills available to adapt domestically the advanced knowledge and technology created abroad.

Galama and Hosek (2009) projected that “significant investment in science and technology and demographic changes are likely to increase the demand for scientists and engineers worldwide” (p. 108). To meet the need, countries are expected to offer STEM educational opportunities for their youth. As higher education becomes increasingly internationalized, study abroad extends such educational opportunities. Given the importance of scientific and technological capabilities in the global knowledge economy or global knowledge society, economies’ and individuals’ increased investment in education, competition between higher education institutions and between countries, deregulation on migration, changes in demographics, and individuals global search for better opportunities in work and life, one may expect that the traffic of STEM student flows will only continue to increase and become even more complex.

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Appendix A: The push Model: Number of Students by Country of Origin Enrolled in Tertiary-Level STEM programs in Australia, the UK, and the US

Country of origin	Number of students	Country of origin	Number of students
Albania	204	Cyprus	3,827
Algeria	116	Czech Republic	334
Argentina	335	Denmark	404
Armenia	86	Djibouti	3
Australia	615	DR Congo	99
Austria	488	Ecuador	418
Azerbaijan	74	Egypt	1,212
Bahrain	440	El Salvador	126
Bangladesh	3,018	Eritrea	86
Belarus	125	Estonia	160
Belgium	833	Ethiopia	749
Benin	76	Finland	365
Bhutan	85	France	5,337
Bolivia	261	Gambia	161
Botswana	584	Georgia	96
Brazil	1,416	Germany	5,220
Bulgaria	990	Ghana	1,374
Burkina Faso	146	Greece	5,702
Cambodia	116	Guatemala	180
Cameroon	631	Guinea	26
Canada	5,089	Guyana	88
Cape Verde	22	Honduras	206
Central African Republic	9	Hungary	334
Chile	439	Iceland	168
China	68,856	India	90,302
China, Hong Kong SAR	5,794	Indonesia	4,332
Colombia	1,880	Iran	5,546
Comoros	3	Ireland	4,322
Costa Rica	269	Israel	518
Côte d'Ivoire	191	Italy	2,502
Croatia	116	Jamaica	1,045

Appendix A (Continued)

Country of origin	Number of students	Country of origin	Number of students
Japan	3,186	Poland	2,837
Jordan	1,394	Portugal	1,204
Kazakhstan	581	Qatar	706
Kenya	2,278	Republic of Korea	15,601
Kuwait	1,578	Republic of Moldova	103
Kyrgyzstan	47	Romania	1,185
Laos	25	Russian Federation	1,435
Latvia	381	Saudi Arabia	9,255
Lebanon	918	Singapore	4,183
Lesotho	11	Slovakia	355
Lithuania	572	Slovenia	103
Luxembourg	221	South Africa	740
Madagascar	36	Spain	2,335
Malaysia	13,740	Swaziland	26
Mali	142	Sweden	1,132
Malta	305	Switzerland	591
Mauritius	1,001	Tajikistan	22
Mexico	3,041	Tanzania	517
Mongolia	273	Thailand	3,710
Morocco	382	The FYR of Macedonia	110
Mozambique	17	Tunisia	116
Namibia	12	Turkey	4,258
Nepal	6,265	Uganda	497
Netherlands	997	Ukraine	457
New Zealand	785	United Arab Emirates	1,690
Niger	36	United Kingdom	1,160
Norway	816	United States	2,775
Oman	770	Uruguay	68
Pakistan	6,130	Uzbekistan	108
Panama	227	Venezuela	1,047
Philippines	1,003	Viet Nam	4,404

Appendix B: Variables, Measures, and Sources for the Pull Model

Variable type	Variable	Measure	Sources	Coding/Note
Dependent	International STEM enrollments	The number of international students enrolled in tertiary-level programs in science, technology, engineering, and mathematics fields (STEM) in a host country in a year.	UNESCO Institute for Statistics	Continuous. Transformed into a natural log.
	The ratio of international STEM enrollment to national STEM enrollment	The ratio of the number of international students enrolled in tertiary-level STEM programs in a host country to the number of national students enrolled in tertiary-level STEM programs in that country in a year.	UNESCO Institute for Statistics	Continuous. Transformed into a natural log.
Independent	English-language instruction	Indicator of English is the language for instruction in all, or nearly all, tertiary education programs in a country.	OECD	"0"- No "1"-Yes
	National students' rate of participation in STEM programs	The percentage is the number of national students enrolled in domestic tertiary-level STEM programs in a year divided by the 5-year age group starting from the age that students typically graduate from secondary school.	UNESCO Institute for Statistics	Continuous. Percentage.
	Academic reputation of higher education in STEM fields	The percentage is the number of universities ranked in the top 500 universities in the Academic Rankings of World Universities divided by total number of universities in a host country in a year.	Shanghai Jiao Tong University	Continuous. Percentage.

Appendix B (Continued)

Variable type	Variable	Measure	Sources	Coding/Note
Independent	Technological capability: Advanced	Indicator of advanced technological capability (featuring high infrastructure and skills and high innovation).	Castellacci & Archibug (2008)	"0"- No "1"-Yes
	Technological capability: Followers	Indicator of mid-status technological capability (featuring medium-high infrastructures and skills and low innovation).	Castellacci & Archibug (2008)	"0"- No "1"-Yes
	Technological capability: Marginalized	Indicator of low or marginalized technological capability (featuring low infrastructures and skills and low innovation).	Castellacci & Archibug (2008)	"0"- No "1"-Yes
	Gross expenditure on research and development(R&D)	The percentage is total domestic intramural expenditure on R&D divided by the gross domestic products (GDP) in a year.	UNESCO Institute for Statistics	Continuous. Percentage.
	Stay rate of international students in the host country	The rate is estimated as the ratio of the number of persons who have changed status (whether for work, family or other reasons) to the number of students who have not renewed their permits (OECD, 2011b).	OECD	Continuous. Percentage.
	Percentage of population aged 65 or above	The percentage is the population aged 65 years and above divided by the total population in a country.	United Nations Population Division	Continuous. Percentage.
Control	Higher education enrollment	The number of students enrolled in higher education institutions in a country.	UNESCO Institute for Statistics	Continuous. Transformed into a natural log.

Appendix C: Variables, Measures, and Sources for the Push Model

Variable type	Variable	Measure	Sources	Coding/Note
Dependent	Student demand for tertiary-level STEM education abroad	The number of students from a country who are enrolled in tertiary-level STEM programs in Australia, the UK, and the US.	U.S. National Science Foundation, U.K. Higher Education Statistical Agency, Australian Department of Education, Employment and Workplace Relations, and the United Nations Population Division	Continuous. Transformed into a natural log.
Independent	Funding for studying abroad	Gross national income *per capita*, purchasing power parity.	World Bank	Continuous
	Emigration rate of tertiary-educated people from a country to OECD countries	The percentage is the number of emigrants aged 25 years and older with at least 1 year of tertiary education and residing in OECD countries other than that in which they were born divided by the population aged 25 years and older with tertiary education.	World Bank	Continuous. Percentage.
	Proportion of emigrants from a country to OECD countries who have attained tertiary education	The proportion is the number of emigrants from the same country of origin who reside in OECD countries and who have attained tertiary education divided by the total number of emigrants from the same country of origin who reside in OECD countries.	World Bank	Continuous. Percentage.

Appendix C (continued)

Variable type	Variable	Measure	Sources	Coding/Note
Independent	National students' rate of participation in STEM programs	The percentage is the number of national students enrolled in domestic tertiary STEM programs in a year divided by the 5-year age group starting from the age that students typically graduate from secondary school.	UNESCO Institute for Statistics	Continuous. Percentage.
	Unavailability of doctoral programs	Absence of doctoral programs in a country.	UNESCO Institute for Statistics	"0"- False, "1"- True
	Academic reputation of higher education	The percentage is the number of universities ranked in the top 500 universities in the Academic Rankings of World Universities divided by total number of universities in a host country in a year.	Shanghai Jiao Tong University	Continuous. Percentage.
	Technological capability: Advanced	Indicator of advanced technological capability (featuring high infrastructure and skills and high innovation).	Castellacci & Archibug (2008)	"0"- No "1"-Yes
	Technological capability: Followers	Indicator of mid-status technological capability (featuring medium-high infrastructures and skills and low innovation).	Castellacci & Archibug (2008)	"0"- No "1"-Yes
	Technological capability: Marginalized	Indicator of low or marginalized technological capability (featuring low infrastructures and skills and low innovation).	Castellacci & Archibug (2008)	"0"- No "1"-Yes
	Scientific and technological journal articles per 100,000 inhabitants	Number of scientific and technical journal articles published per 100,000 inhabitants in a country.	World Bank	Continuous.

Appendix C (continued)

Variable type	Variable	Measure	Sources	Coding/Note
Independent	Civil and political freedom: Free	Indicator of individuals having freedom for political rights and civil liberties in a country.	The Freedom House	"0"- No "1"-Yes
	Civil and political freedom: Partially free	Indicator of individuals having partial freedom for political rights and civil liberties in a country.	The Freedom House	"0"- No "1"-Yes
	Civil and political freedom: Not free	Indicator of individuals having no freedom for political rights and civil liberties in a country.	The Freedom House	"0"- No "1"-Yes
	Linguistic links	Indicator of a home country and a host country sharing a common official language: English.	the Centre d'Etudes Prospectives et d'Informations Internationales (CEPII)	"0"- No "1"-Yes
	Geographic links	Indicator of a home country and a host country locating in the same geographic region.	Author	"0"- No "1"-Yes
	Colonial links	Indicator of a country having ever been a colony of a given host country.	CEPII	"0"- No "1"-Yes
	Social links	The percentage is the number of individuals born outside their current country of residence, from the same country of origin, and residing in Australia, the UK, or the US divided by the total number of emigrants from the same country of origin in all destination countries.	the University of Sussex	Continuous. Percentage.

Appendix C (continued)

Variable type	Variable	Measure	Sources	Coding/Note
Control	Population	Total population in a country.	The United Nations Population Division	Continuous. Transformed into a natural log