EMIGRATION OF CHINESE SCIENTISTS AND ITS IMPACTS ON NATIONAL RESEARCH PERFORMANCE FROM A SENDING COUNTRY PERSPECTIVE

by

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Dedication

This is dedicated to my father, Jinqin Tian, and my mother, Dawei Yang, who nurtured me in an intellectual environment.

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Abstract

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Skilled emigration has become an important policy concern of developing countries for several decades. This dissertation closely examines the major effects of a scientific brain drain on the source country against the background of global talent competition. The sample used in this study is drawn from Chinese scientists in four disciplines of natural sciences at leading global universities. By combining biographical and bibliometric data, the dissertation not only demonstrates migration patterns of Chinese scientists, but also reveals their research productivity profiles between 1998 and 2006.

The findings of this dissertation show that the scientific community in China experienced increasing personnel exchange with the English academia during the observation period. Emigrant scientists from China were selected positively, while returnee scientists were selected negatively. Both patterns seemed to turn stronger over time. However, the research gap between domestic scientists and overseas scientists had been reduced substantially in terms of average productivity or highest performance.

Returnees with domestic degrees, instead of those with foreign degrees, largely drove the rising productivity level in China. In addition, domestic scientists benefited greatly from international collaboration in general, and collaboration with overseas Chinese in particular.

This study also estimated the potential loss brought by the emigration of Chinese scientists. Simulation outcomes based on the empirical findings demonstrate that the intellectual loss to China looks striking under an ideal condition, but it would be reduced substantially in more realistic scenarios with limited budget and less international collaboration. The following counterfactual analysis shows that Chinese scientists would have made a greater contribution to the world, if more of them could move abroad. However, China's research output would be lower than the actual level, because additional returnees and international collaboration would not enough to compensate the output of its lost manpower.

According to the major findings of this dissertation, restrictive measures of international migration are counterproductive in improving global welfare. Specific policies are recommended to both China and the host countries, so that they can share the gain from emigration in a triple-win situation. This dissertation enriches our understanding of international migration in the scientific community, and helps explain China's experience in achieving rapid scientific development. Its theoretical framework and methodology may help policymakers in other countries evaluate outflows of their skilled nationals and address related issues effectively.

Chapter 1 Introduction

"*Science has no borders, but scientists have their own fatherlands.*"

- *French Chemist Louis Pasteur*

1.1 Knowledge economy and skilled migration

A global "knowledge economy" has been gradually emerging in the world since the late 20th century, which is intensely based on the production, distribution, diffusion, exchange, and usage of knowledge and information (OECD 1996). Endogenous growth theory and studies on economic history have convincingly argued that science and technology (S&T) are the primary engines of economic growth, because it is the knowledge stock accumulated in human societies which maintains the long-term increasing return to production factors (Romer 1986; Goldstone 1987; Lucas 1988). Following this economic rationale, many countries have actively expanded their national talent pools, as scientists and engineers are carriers of S&T knowledge.

Besides education reform and R&D investment, governments in the developed world often meet the increasing demand for skilled workers by employing highly educated migrants from foreign countries on a temporary or permanent basis (Abella 2006). For example, the United States set the annual quota of employment-based immigration to 140 thousand in the immigration system reform in 1991, and adopted an

H-1B visa program targeting temporary skilled migrants (CRS 2006, 2007). Other traditional immigration countries, such as Canada, Australia, and New Zealand, have been screening immigration applicants by a point-based system for a long time (Miller 1999; Beach, Green and Worswick 2007), and the United Kingdom imitated their policies in 2008 (Wadsworth 2010). The European Union also initiated its "Blue Card" program in 2007 to facilitate the inflow of non-EU skilled workers to its member countries (Kahanec and Zimmermann 2010). On the other side of the world, South Korea not only encourages skilled overseas Koreans to return but also lures foreign scientists to work in local research institutions (Daugeliene and Marcinkeviciene 2009). Hong Kong and Singapore have long been known for their open attitude toward skilled foreign workers. Overall, at least sixteen countries and regions had implemented a merit-based immigration program by 2007 (RPC 2007).

The receiving countries have not only mitigated talent shortages by incorporating skilled migrants, but also benefited enormously from their inflows. For example, immigrants are disproportionately represented among outstanding scientists and engineers in the US (Stephan and Levin 2001; Stephan 2010). Due to enormous imbalances in the directions of skilled flows (Gill 2005), however, the large welfare brought by skilled migration is unevenly distributed between nations, and the problem of "brain drain" has persisted in the sending countries, most of which belong to the developing world. As emigration of native talent is believed to be detrimental to the interests of source countries, many scholars have raised their ethical concerns about the fairness of brain drain (e.g. Dickson 2003). Bhagwati (1979) even views it as a violation of international justice if skilled migration redistributes resources from origin countries to destination countries without adequate compensations.

Every coin has two sides. Students of migration have gradually realized that skilled emigrants can also bring benefits to their home countries, such as remittances, returnees, technology transfer, and foreign investment. For example, some developing countries, particularly China and India, are actively recruiting their skilled expatriates back home with favorable conditions (Xiang 2003; Kapur and McHale 2005, 163-176), which has in turn triggered a concern of "reverse brain drain" in some host countries like the US (Heenan 2005; Wadwa et al. 2007). A brain drain can actually turn into a gain for developing countries, if its positive effects outweigh the negative ones. In this sense, skilled emigration should be viewed not as loss of talent, but an important means of development.

However, people often view skilled emigration as a problem to be solved, as the overall benefits from skilled migration to source countries, or those left behind, are not entirely clear (Bhatnagar 2004). Nor do source countries fully understand how to take advantage of their national human resources in foreign countries. As Ackers (2005a) points out, "it remains unclear whether the loss of skilled emigrants can be compensated through circulatory human capital and knowledge." The research agenda of migration studies has realized the gap between available knowledge and policy needs in this regard. As a response, this dissertation is devoted to a better understanding of the consequences of brain drain in general, and the migration of scientists in particular.

The effects of skilled emigration vary considerably by occupation, and migration patterns in one industry may differ considerably from those in others, so it is necessary to analyze the impacts of brain drain according to occupational and industrial contexts (Iredale 2001). This study focuses on transnational flows of leading natural scientists for two reasons. First, leading scientists represent a small but highly influential group in a country. They are not only an essential source of research capacity in science, but also a crucial economic asset spurring national development. Leading scientists carry out key functions in the knowledge economy, including knowledge production, diffusion, and transfer. Many developing countries have established a relatively small and weak research infrastructure, based on the belief that scientific knowledge will bring them advanced education and technological development. Hence emigration of leading scientists, or potential leading scientists, has very important consequences for their home countries.

Second, it is relatively easy to collect and compare demographic data of scientists, as well as indicators of their productivity. The profession of scientists is relatively more mobile and internationalized than other professions, and natural scientists have a higher propensity to migrate than social scientists because their knowledge is highly transferrable between countries. We can identify the migration trajectories of emigrant scientists according to their online information, since most of them have official/personal web pages on the websites of their affiliations. This study also used a survey to collect additional data, such as their working experience and visa status.

While most labor studies have difficulties in generating productivity indicators, it is advantageous to take natural scientists as the target population, because their publication records are available through bibliographic databases, such as SCI and Scopus, and they are arguably internationally comparable. Economists have closely examined the wage changes of immigrants (e.g. Clemens, Montenegro, and Pritchett 2009), but monetary return to human capital does not necessarily indicate individual productivity, because many factors determine one's wage or income, including currency exchange rate and labor market situation. In addition, an innovator's salary does not comprehensively reflect his contribution to a society[1], for the social return is not taken into account. By contrast, we can closely examine the effects of a scientific brain drain with more accurate productivity data.

Last but not least, it is necessary to introduce the definition of "migration" in the study. The concept "scientific mobility" refers to professionally motivated temporary or permanent movements of scientists between higher education and research institutions. The literature uses this term in a wide range of continuum, including conference participation, special visits, temporary overseas study, and permanent employment in a foreign country (Ackers 2005a). Here we follow the common practice of international organizations and adopt a 12-month cutoff convention to separate "migrants" from "visitors" (Tani 2008). The study only analyzes overseas stay for at least a year and leaves short-term visits aside.

1.2 The case of China

[1] Connotations such as "his or her" are cumbersome, so I use my own sex as the basis for all third-person singular pronouns unless there is an obvious reason not to do so.

Migrant scientists are motivated to move for a variety of reasons, including educational opportunities, job opportunities, and family-related factors (Mazzarol and Soutar 2002; Kannankutty and Burelli 2007). Some particular factors also affect their decision of migration, such as agglomeration benefits of knowledge production and organizational effectiveness of national innovation systems (Mahroum 1998; Hart 2007).

This dissertation does not attempt to explain why scientists migrate, why their movements persist toward certain regions, or why some of them choose to return home, though some findings are related to these questions. Instead, its primary research goal is directed to evaluating the positive and negative impacts of emigration of scientists from a sending country perspective. For the purpose of the research, we chose Chinese scientists as the object of study for three reasons.

First of all, migration of Chinese scientists are very dynamic in terms of length, frequency, destination, and program (Séguin et al. 2006; Zweig, Fung, and Han 2008). Chinese overseas scientists constitute a large, if not the largest, scientific diaspora in the world, and its size is still expanding rapidly. A considerable number of Chinese scientists can be found in every major host country, while emigrant scientists from other regions, such as South Africa and Colombia, are more likely to stay in a single host country (Meyer 2001). The number of returnee scientists has also been increasing at a high rate since the late 1990s (Simon and Cao 2009, 241). Hence the dynamics of Chinese scientists' movements provides us a sound opportunity for observing the consequences of skilled emigration.

Second, China's scientific growth is remarkable in recent years, which deserves intensive investigation of the changing composition of its research workforce. The number of Chinese SCI papers increased dramatically at a double digit pace, increasing from over 20,000 SCI indexed papers in 1998 to 112,000 papers in 2008 (Adams, King, and Ma 2009). In 1998, China ranked 9th in the world in terms of the number of SCI papers, but in 2002 its position ascended to 5th (Huang, Varum, and Gouveia 2006), and its scientific stature rose to a position raveled only by the US in 2008 (Shelton and Foland 2009). China far surpasses another Asian giant, India, both in quantity and quality of publications, and it now seems competitive with France, Italy, Japan, and Australia (Kostoff 2008). From a policy perspective, it is pertinent to ask how the migration of its scientists has fostered China's scientific development, which may provide useful models to other developing countries that are lagging behind in the arena of science.

Third, the expansion of China's research capacity is largely driven by its ambitious national strategy targeting the higher education sector. Altbach (2007) observes that "Research universities have emerged on the policy agenda in many developing countries, especially larger nations that seek to compete in the global knowledge economy." As a typical example, China has an explicit goal of turning its leading universities into world class institutions. Besides pouring huge R&D investment into domestic universities, China has actively recruited overseas Chinese scholars from the developed world, as well as inviting them for short visits, in order to take advantage of its scientific diaspora. We may draw some lessons from China's experience if this study can help reveal the policy effects of its talent programs.

This study focuses on the mobility status of Chinese scientists in three observation years, 1998, 2002 and 2006, because return migration and international collaboration in China had become phenomenal only from the late 1990's (Arunachalam and Doss 2000). The sample covers 451 individual scientists at global leading universities, who were selected from about six thousand Chinese researchers in mainland China and seven English-speaking countries. The temporal and spatial scale of this study can help us map the geographic distribution of Chinese scientists and depict their migration patterns. It also opens up new research possibilities in the use of bibliometric data sources, and contributes to the deep understanding of the overall effects of skilled emigration. In addition, the study simulated different scenarios based on the empirical findings, which has strong policy implications for both China and the host countries.

The content of this dissertation is organized as follows. Chapter 2 raises the research questions and related hypotheses after reviewing the underlying literature. Chapter 3 describes the data collection procedure and the weighting scheme. Chapter 4 introduces the variables and their measurements. Chapter 5 analyzes the migration flows of Chinese scientists and their selectivity. Chapter 6 details the contribution of returnee scientists and international collaboration to China's scientific enterprise. Chapter 7 estimates China's intellectual loss by simulating different scenarios and discusses their policy implications. Chapter 8 presents our conclusions.

Chapter 2 Literature Review and Research Questions

After a comprehensive review of the literature, Massey et al. (1993, 432) concludes that "at present, there is no single, coherent theory of international migration, only a fragmented set of theories that have developed largely in isolation from one another, sometimes but not always segmented by disciplinary boundaries." This is also the case of current research on brain drain. The first two sections of this chapter draw from the rich literature of migration studies from different disciplinary perspectives, with a focus on the impacts of emigration on the sending country in general and on its S&T sector in particular. The last section raises key research questions and hypotheses based on a theoretical framework.

2.1 Theories and evidences of skilled emigration

Although the term "brain drain"originated in the context of the European skilled emigration to the United States, it quickly shifted to designate the international transfer of human capital from developing to developed countries (Grubel and Scott 1966; Johnson 1979)[2]. Conventional wisdom tends to strongly associate "brain drain" with negative impacts (Patinkin 1968). Skilled emigration is believed to drain developing countries of

[2] Since "brain drain" is a negative connotation, some scholars prefer to use "skilled emigration" instead (Clemens 2009). This paper uses the two terms interchangeably.

their already small talent pool and thus deprive them of the human resource capable of developing their economies, which contributes to increasing economic and technological gaps in the world (Solimano 2001). Several theoretical models following the new growth literature also emphasize the negative effects of brain drain (Miyagiwa 1991; Haque and Kim 1995; Wong and Yip 1999). For example, Miyagiwa (1991) argues that brain drain hurts skilled workers left in the home country because they can not benefit from scale economy and technical externality associated with a larger skilled workforce. A series of empirical studies have tested the impacts of brain drain at national level with the availability of standardized census data across countries. For example, Desai et al. (2009) evaluate the fiscal cost of the brain drain from India and find that the loss equaled to 2.5% of total Indian fiscal revenues, a conservative estimate in their view. Beine, Docquier, and Rapoport (2003) find that brain drain has particularly negative growth effects in countries with more highly educated people and higher emigration rates.

Brain drain in important sectors and professions can result in severe occupational shortages, which hinders the source country's economic growth severely. For instance, the availability of medical personnel brings positive externalities to national economy in excess of their salaries, and the emigration of doctors can possibly lower the productivity of all occupations, as the O-ring theory implies (Kremer 1993). One study estimates that the annual loss of public subsidies for medical education is as high as US$500 million for the medical brain drain from Africa (Chen and Boufford 2005). Apart from the direct financial loss, Bhargava and Docquier (2008) find that higher brain drain rates of medical personnel from Sub-Saharan African countries are closely linked with a larger number of deaths due to AIDS, suggesting that health worker emigration partially causes poor health outcomes and reduces economic growth rates.

However, dynamic patterns of international migration have renewed the debate on brain drain from the 1990's. The conception about skilled migration has shifted from human capital loss to benefits brought by brain circulation, which can be realized largely through return migration (Gaillard and Gaillard 1998). Physical repatriation of previous emigrants brings the home country not only their original skills but also what they have acquired in the host country. Hence the original loss of brain drain can be partially or even more than offset by attracting former skilled expatriates back home. Mayr and Peri (2008) argue that a reasonable share of return migrants (e.g. 20 to 30% of emigrants) can be critical in evaluating the benefits of skilled flows related to the source country, as returnees may gain a "productivity premium" through overseas experience. Several studies also theorize that return migration transfers knowledge from receiving countries and contributes to the endogenous growth of source countries (Domingues Dos Santos and Postel-Vinay 2003; Dustmann, Fadlon, and Weiss 2011).

Many returnees play the role of transnational entrepreneurs by mobilizing their marketing knowledge and investment capital, after they establish connections with foreign networks (Kapur 2001; Wahba and Zenou 2009). This is particularly the case in high-tech sectors of the source countries (Commander et al. 2004; Luo and Wang 2002). Saxenian (2003, 2005) reports a famous case that Chinese transnational entrepreneurs commute back and forth connecting high technology clusters in Taiwan and mainland China to the Silicon Valley in the United States. She calls these migrant entrepreneurs

‘Argonauts’ because they have accelerated local technological catch-up and reorganized global production networks (Saxenian 2006). However, the role of returnees in knowledge diffusion should not be exaggerated, as the demands of local firms may differ from the skill sets of return migrants (Kale, Wield, and Chataway 2008).

Benefits of skilled flows does not have to be achieved through physical movement of expatriates, since the diaspora can be useful assets for their home country in sending remittances, facilitating technology transfer and establishing trade networks, which has long been documented in the migration literature (Grubel and Scott 1966; Gaillard and Gaillard 1998; Ratha 2003). Some early literature show that remittances tend to increase with the level of skills (Johnson and Whitelaw 1974; Rempel and Lobfell 1978), as skilled migrants are assumed to have higher income and hence are likely to remit more. However, Rodriguez and Horton (1994) find that that the education level of Philippine migrants has no impact on the amount of remittances. Recent studies even suggest that remittances decline as the proportion of migrants with a tertiary education increases (Faini 2007), whose findings are confirmed by Niimi, Ozden, and Schiff. (2008). It is still an open question whether remittance counterbalances fiscal loss of brain drain. In addition, emigrants send remittances primarily to their family members, which may increase local economic inequality.

Besides direct income transfer, overseas skilled migrants help attract foreign investment to the source country, as they reduce transnational transaction costs and establish mutual trust between their host country and home country (Rauch and Trindade 2002; Javorcik et al. 2011). For example, the skilled diaspora of countries like India has contributed to the growth of the information technology sector and outsourcing industry in their homelands (Saxenian 2006). Kugler and Rapoport (2007) find FDI in both the service and manufacturing sectors are positively associated with the initial skilled migration stock of a sending country in the US, which has been further supported by Javorcik et al. (2011).

Skilled emigrant workers also facilitate international technology transfers to their home countries. It is often difficult to realize knowledge diffusion across countries due to physical distances, technological gaps, and political constraints. For example, inventors in the same country are far more likely to cite each other's patents than those from different countries (Jaffe and Trajtenberg 1999). Using data on 1.5 million patents to estimate knowledge flows, Peri (2005) reports that only 9% of knowledge had been learned by people outside the country of origin between 1975 and 1996. However, Johnson, Siripong, and Brown (2006) show that the hindering effect of physical distance has weakened in global technological diffusion process, which enhances knowledge transfer among people sharing a common language (MacGarvie 2005).

Kerr (2008) examines the knowledge diffusion along the ethnic diaspora channel. He finds that the diffusion has a positive impact on manufacturing productivity in the source countries, particularly in the high-tech sector. Agrawal et al. (2011) also report empirical evidences that emigration of skilled workers helps innovators in India access valuable overseas knowledge, particularly for the most important inventions. More interestingly, migration of talented people to more innovative countries can advance scientific progress at global level, which in turn benefits their home countries by knowledge transfer (Grubel and Scott 1966). Kuhn and McAusland (2009) points out that outmigration raises the productivity of emigrants, which can compensate economic loss of the home country if their productivity gain is high enough and native consumers also share their knowledge-intense products

Students of migration used to adopt the term “brain gain”, when a country benefits more from skilled migration than its human capital loss. A body of recent literature develops a new notion of “brain gain” and emphases the importance of migration prospects, even if they are merely perceived by potential migrants. The conventional wisdom assumes either domestic human capital before migration is exogenous to overseas opportunities (Wong and Yip 1999), or all skilled workers seeking migration opportunities move abroad (Haque and Kim 1995). However, it is reasonable to conjecture that not all potential migrants can realize their “American dream,” largely because of restrictive visa policies of destination countries. As the “brain gain” theory argues, migration opportunities raise expected return on education, thereby inducing talented students to learn more skills. This “gain” effect may counterbalance the “drain” effect and result in more human capital in the source country than the scenario without brain drain (Mountford 1997; Stark 2004).

A series of studies provide empirical evidences and support the “brain gain” argument (Beine, Docquier, and Rapoport 2003; Clemens 2007; Beine, Docquier, and Oden-Defoort 2011). Beine, Docquier, and Rapoport (2003) find that migration prospects have a positive effect on human capital formation. As a result, the prospect of brain drain may actually have positive effect on economic growth in poor countries with lower emigration rates. Clemens (2007) suggests that Africa's poor public health conditions are not related to the emigration of its medical personnel and the medical brain drain actually contributes to training more health workers. Two illustrating case studies also collect supportive evidences from Cape Verde (Batista, Lacuesta and Vicente 2010) and Fiji Islands (Chand and Clemens 2008), which implies substantial human capital gain from lowering migration barriers.

However, Schiff (2006) has systematically criticized several basic assumptions of the brain gain model, and argues that the positive effects of skilled emigration are exaggerated. First, abilities are heterogeneous and foreign labor market can screen workers efficiently, which lead to the loss of the most talented to the sending country. Second, a high degree of uncertainty associated with migration opportunities is unfounded. Finally, given the fact that higher education is entirely or partly financed by the national governments in the developing world, brain drain is detrimental to the sending countries because of the fiscal loss. In addition, Docquier and Rapoport (2011) suggest that the causal relationship of brain gain might be reversed since more education investment and higher economic growth can also result in more skilled emigrants.

Opportunities of migration not only facilitate human capital accumulation, but also change the composition of educated workforce in source countries. The prospect of migration induces people to invest in particular skills more desirable in destination countries. Gibson and McKenzie (2011) find that high school students in Tonga and Papua New Guinea prepared for emigration by taking additional classes and choosing sciences and commerce. Mariani (2007) argues that migration prospects increase people's motivation to participate in productive activities, because rent-seeking skills are not transferrable internationally. He finds that the emigration rate of skilled workers is positively associated with the proportion of productive occupations, instead of rent-seeking ones. Following this rationale, Peng (2009) also stresses the importance of migration prospects in improving the allocation of national human resources.

Expectation of emigration may also discourage talented students from accumulating the most needed skills for their home country, if it is not in high demand in the host country, thereby hindering the growth of the source economy (Maria and Stryszowski 2009). For instance, a developing country can not benefit from the "brain gain" effect, if its domestic industries demand more skilled workers good at technical adoption than those doing well in innovation, but the latter group are more likely to grow thanks to the prospect of outmigration. The larger the technological gap between the source country and the destination country, the stronger the negative effect is. Such distortion of incentives can be corrected if the national curriculum focuses on the needs of developing economies.

Last but not least, skilled emigration has mixed impacts on institution building. On the one hand, freedom of exit may relax domestic pressure for political reform, as those dissatisfied with the regime of their home country simple choose to move abroad. Higher salaries in foreign countries and associated remittances also provide a safety valve, which reduces the middle class's incentive to push economic reform. Hence a brain drain after a social crisis can weaken democratic consolidation in some developing countries (Kapur and McHale 2005, 87-109).

On the other hand, the diaspora from a source country can become politically active and exert international influence on domestic institutional change. The transnational networks also send "social remittance" back to the home country, which spreads certain social values including democracy and human rights. Using World Bank governance indicators, Li and McHale (2009) show that brain drain has a positive effect on political institutions but a negative one on economic institutions at home. In addition, the source country can be driven to push particular institutional reform, such as its intellectual property regime, in order to retain skilled workers (McAusland and Kuhn 2011).

2.2 Migration of scientists

The term "brain drain" was originally derived from emigration of scientists. In the early 1960s the British Royal Society issued an alarming report publicizing the emigration of British scientists to the United States and other countries (The Royal Society 1963). It sparked off a nationwide discussion in which a journalist coined the phrase "brain drain".

Emigration of scientists may indicate a loss of research capability and scientific knowledge for a source country. The famous historical cases include the exodus of Jewish scientists to America in the 1930's or the outflow of Russian scientists to the West after the Cold War. In our time, Europe is generally viewed as a loser in the global talent race. It produces more science graduates per capita than the United States, but it has fewer researchers per capita than the US, which is largely caused by the outflow of European researchers (Docquier and Rapoport 2011).

Despite persisting emigration of scientists from Europe and the developing world, empirical studies on spatial movements of this professional group remains scarce (Laudel 2005). As a large research project in Europe, the “MOBISC” study has surveyed a cohort of mobile scientists across five countries. However, it focuses mainly on individual experiences instead of national impacts, such as career, mobility, work and life considerations (Ackers 2005a, 2005b). Few studies have closely examined the consequences of scientific emigration on the research capability in the source country, though several notable exceptions did address this issue (Zucker and Darby 2007; Hunter 2009).

The recent literature of “brain circulation” stresses a two-way flow of skilled workers between an origin country and a destination country, which provides an important mechanism of knowledge transfer and international collaboration (Meyer, Kaplan and Charum 2001; Ackers 2005b). Migrants returning with cutting-edge knowledge and international networks are considered important transmitters of technology and knowledge (Davenport 2004). Since it is often impossible or too costly to codify all knowledge and transfer tacit knowledge, returnee scientists can play a crucial and effective role in knowledge diffusion by personal interaction or joint research projects with domestic researchers.

Although inflows of returnees can not match outflows of emigrant scientists, temporary migration of domestic scholars also fosters knowledge flows as they gain experience abroad after short-term stays. Frequent visits help the local scientific community join global networks and collaborate with foreign scientists (Regets 2007;

Defazio, Lockett, and Wright 2009). Skilled emigration can be beneficial to a source country if its overseas scientists facilitate temporary visits of their domestic peers by developing an ethnic scientific network (Thorn and Holm-Nielsen 2006).

More importantly, a country's scientific diaspora can provide external knowledge directly to those remaining in their home country (Meyer, Kaplan and Charum 2001; Kuznetsov 2006; Ciumasu 2010). Emigrant scientists transfer their expertise to the home scientific community by maintaining long distance interactions in the transnational research network (Thorn and Holm-Nielsen 2006). Thanks to modern high-speed communications, the knowledge diffusion effect of the diaspora can possibly become stronger than that of geographic proximity, if emigration raises the productivity of overseas scientists and they maintained strong ties with those at home (Kuhn and McAusland 2006).

Developing countries can take advantage of their scientific diasporas in a relatively easy way, since transnational networking activities do not require large infrastructural investments, and capitalize only on existing overseas resources. However, a crucial element of utilizing diaspora asset is an effective platform to facilitate information transfer and research collaboration between both sides. According to Meyer and Brown (1999), no less than forty-one networks of scientific diaspora had emerged in 35 countries in the 1990's, which connect skilled expatriates with their origin country. Overseas scientists of the same ethnicity often associate themselves in professional organizations and often communicate and collaborate with their domestic counterparts. Two successful examples are the Red Caldas of the Colombian S&T communities and the South African

Network of Skills Abroad (Chaparro, Jaramillo, and Quintero 2004; Meyer 2001).

Recent studies on scientific diaspora networks capture some beneficial effects of emigrant scientists as significant partners in development cooperation (Seguin et al. 2006), but they also report that expatriates do not have strong links with the home country (Meyer 2001). The extent of utilization of expatriates' expertise largely depends on the development of a domestic scientific community (Meyer and Brown 1999). If a sending country does not have the capacity to maintain an interactive relationship with its expatriates, the growth of the scientific diaspora may engender a culture of emigration, and generate a chain reaction of brain drain without much positive feedback (Mahroum, Eldridge, and Daar 2006). Despite the empirical literature based on case studies, systematic evidences on brain circulation in the international science community are still scarce.

2.3 Research Questions and Hypotheses

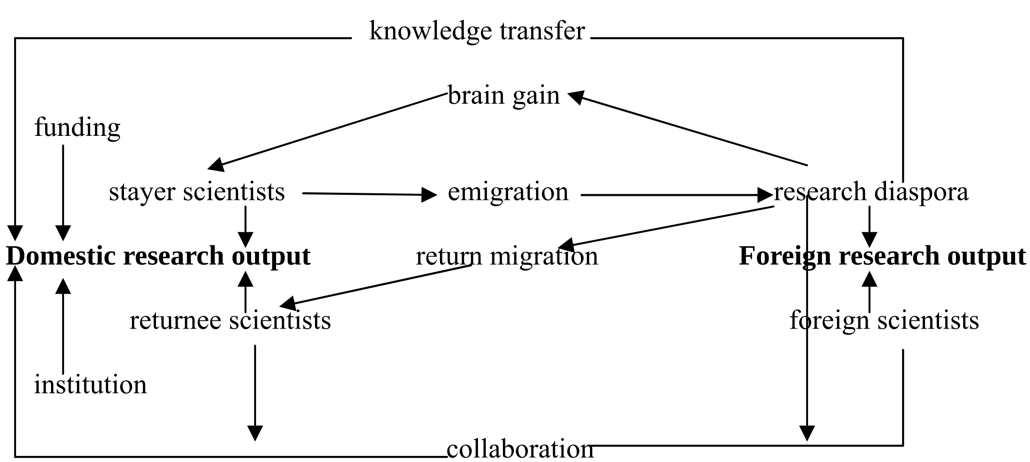

Figure 2.1 - Impacts of a scientific brain drain on domestic research output

Based on the literature reviewed in Section 2.2, we summarize the major effects of a scientific brain drain in a theoretical framework. As the left side of Figure 2.1 shows, domestic research output depends on three fundamental factors - funding, institution, and research personnel. This dissertation mainly focuses on the direct impacts of research personnel, though the factor of manpower also interacts with the other two factors in a complex way. For example, return migration can push institutional reform or change funding allocation, and improvement of research institution and funding mechanism may in turn attract more returnees back home.

Here we briefly demonstrate how migration of scientists affects the research output in the source country by different channels in an ideal setting. At the beginning, all native scientists receive education and work in the home country, and there is no personnel exchange between the domestic scientific community and the external world. As the source country is gradually integrated into the global economy, some native scientists are attracted by more conducive research environments in foreign countries and move abroad for study or work. These emigrants constitute the "scientific diaspora" and contribute directly to the scientific production in the destination country. A few emigrants choose to come back after they have accumulated some overseas experience abroad, since sustained economic growth occurs in their home country and they are lured back by emerging opportunities in the domestic research sector. Now the national scientists are separated into two parts: the domestic part and the overseas part. Ongoing emigration and return flows constantly change the composition of both parts.

“What one loses on the swings, he gets back on the roundabouts”. From the perspective of the source country, the emigration of its scientists, particularly the best and brightest, is a national loss. However, this “drain effect” is partially offset by return migration. Returnee scientists have been better trained abroad and are more productive than those left behind, though they represent only a fraction of all emigrants. Returnees not only transfer their knowledge to the home country, but transform their applicable expertise according to the local context (Iskander 2011). As stayer scientists learn from or imitate their returnee peers, return migration helps raise the average productivity of the national research workforce. In addition, previous emigrant scientists have become role models for later comers. Young talented students are prone to choose a research career, since they envisage a brighter future by moving abroad. Not all of them can attend foreign universities because of more intense competition, however, and many end up in the domestic labor market, which results in a “brain gain” situation.

Both emigrants and returnees help establish professional ties between the source country and the destination country, thereby facilitating international research collaborations. Such collaborations are more likely to occur between domestic and overseas scientists, since they share the same ethnic background and have cultural affinity. Their coauthored publications bring the research partners in the source country more international visibility and impact. The scientific diaspora also assist their domestic peers in absorbing cutting-edge knowledge by short visits or telecommunications. Hence foreign academic achievements, particularly those by overseas scientists, become more accessible to the domestic scientific community. The initial loss of manpower to the source country may be more than compensated by these positive feedbacks consequently; and moreover, the average productivity level of the native scientists on both sides have increased compared with the situation when they are isolated from the international scientific community.

The theoretical framework is completely based on the existing literature, and we do not raise new theories here. Instead, this dissertation mainly explores the intellectual impacts of the scientific brain drain from China based on empirical data, as well as its benefits from return migration and the scientific diaspora. In addition, we also provide some mixed evidences on the brain gain effect. It does not cover the channel of knowledge transfer, as the citation data were only used for generating qualitative indicators, instead of measuring knowledge flows. To be specific, the research was designed to answer the following four key research questions and testing five related hypotheses.

Q1. Compared with the base population of scientists, how were emigrants and returnees selected in terms of key demographic indicators?

This question is crucial to identifying the nature of the two migration flows. Here the base population of emigrants is all scientists who received undergraduate education in China; that of returnees refers to all those who obtained their highest degrees abroad, or who studied/worked abroad for at least two years, depending on the definition of returnees. The key demographic indicators include age, gender, educational background, and more importantly, research productivity.

Students of migration have reached a consensus that skilled emigration generally has strong and positive selectivity (Kapur 2010, 69-102). Here we expect not only emigrant scientists are positively selected, but their selectivity becomes stronger over time. The intensified selectivity may result from two trends – increasing information transparency and diverging migration opportunities. At the beginning of emigration, employers at the host country can not differentiate the skill levels of migrants effectively due to information asymmetry, so the selectivity is weak. After some years, the host country can screen qualified workers by a sorting process like the point system, and foreign employers can estimate the skill level of a foreign applicant more accurately after they become familiar with the labor qualification indicators of potential migrants.

With regard to scientific migration, foreign universities usually play the role of gate keepers and they have gradually accumulated experiences in admitting international students. Hence graduates from prestigious colleges in the source country are more likely to attend foreign doctoral programs than those from less prestigious ones. Overseas alumni networks of prestigious colleges can provide additional assistance to the admission of younger schoolmates and diminish the risks of application. Moreover, past successful cases stimulate the motivations of domestic students to seek overseas study opportunities. Here, then, is our first hypothesis:

H1: recent cohorts of Chinese emigrant scientists were more positively selected than old cohorts in terms of education background. In other words, the probability of overseas study or employment is increasing with the quality of education, and the *association becomes stronger over time.*

By contrast, negative selection often characterizes return migration (Borjas and Bratsberg 1996). Borjas (1989) finds a negative selection process by which the least successful foreign scientists were more likely to return from the United States. Stark Helmenstein, and Prskawetz (1997) also argue that low-ability workers are more likely to return from the foreign labor market, once employers know their real productivity and dismiss them. However, based on the data of migration between Eastern and Western Europe, Mayr and Peri (2009) demonstrate that the skills acquired in foreign countries contribute to a “return premium" in the home country, which leads to positive selection in return migration. There are also some empirical evidences supporting this trend (Dustmann and Weiss 2007; Gundel and Peters 2008)

Considering China is still lagging behind the developed countries in the arena of science, we hypothesize that returnee scientists are more likely to be negatively selected. However, the negative selectivity is expected to be weakened over time, as more emigrants are attracted by the rapidly growing economy and lured back by China’s talent programs targeting outstanding returnees. The second hypothesis expects that:

H2: returnee scientists who have come back in recent years were less negatively selected from overseas Chinese than those who returned in earlier periods in terms of educational background and research productivity.

The third hypothesis tests the positive effect of migration prospect. The brain gain theory theorizes that migration prospect can induce human capital formation in particular fields. For example, a Chinese student chooses the major of mathematics because scientists in this field are more likely to find jobs abroad. He may end up in a domestic doctoral program, if foreign universities do not admit him. Such a brain gain effect is expected to be more significant in fields with higher emigration rates, particularly for graduates from prestigious universities.

H3: domestic doctoral students in a discipline with a higher emigration rate are more likely to graduate from prestigious colleges in the source country than those in a discipline with a lower emigration rate.

Van Bouwel (2010) calls for new studies on migration "to tackle new research questions with regard to the effect of international mobility on research productivity and on researchers' collaboration networks." Our second research question focuses on the channels of return migration and the disapora, since we also want to know how the domestic research output was affected by the migration patterns.

Q2. What benefits do scientists with overseas experience bring to the scientific production in the source country?

There are two kinds of scientists with overseas experience – returnees and emigrants. Returnee scientists participate directly in the domestic scientific community after staying abroad, and they may have some difficulties in reintegrating themselves into the local research environment (Morano-Foadi 2005; Delicado 2010). For example, Melin (2005) finds that it is hard for 10-20% of Swedish post-docs to transfer their knowledge to their departments after repatriation. Nonetheless, we may still expect that returnees produce more research output than stayers in China, since they can take advantage of their skills learned abroad and enjoy favorable research and living conditions. Here, then, is the fourth hypothesis:

H4: other things being equal, domestic scientists with overseas experience exhibit higher productivity than those without such experience.

Emigrant scientists also make considerable contribution to the source country indirectly. Research collaboration in scientific networks is a significant determinant of scientists' productivity. It is well documented that scientists who collaborate with each other are more likely to publish high-quality papers than individual researchers (Andrews 1979; Lawani 1986). Scientists in developing countries particularly benefit from joint research activities with those in the developed world (Bordons et al. 1996). Moreover, Gaule and Piacentini (2011) show that overseas Chinese graduate students of chemistry exhibit higher research productivity if their advisors are also Chinese, possibly because scientists of the same ethnicity have less barriers of communication. As Welch and Zhang (2008) suggests: "…sharing the same cultural and linguistic backgrounds contributed to a greater closeness in scholarly communications." Based on these observations, we expect that:

H5: other things being equal, domestic scientists with international collaboration exhibit higher productivity than those without such collaboration; collaboration with overseas Chinese brings additional productivity premium.

The following two questions are counterfactual by nature, and they are based on the answers to the previous empirical questions. The term “brain drain” has a negative connotation because people think skilled emigration is detrimental to the national development in the source country, but it might not be the case given the positive feedbacks. Next we attempt to predict the intellectual loss of the scientific brain drain from China. A through investigation of China’s loss in the past three decades is beyond the scope of this dissertation. Instead, it estimates whether China lost or gained from its scientific brain drain in 2006, since we have collected individual publication records in that particular year. We try to solve the problem by constructing a counterfactual scenario.

Q3. Would China achieve higher research output in 2006 if the scientific brain drain did not occur?

The extreme scenario without emigration has merely theoretical value. Our counterfactual analysis will have more policy implications if we simulate scenarios moderately different from the reality. Since governmental policies in both China and the host countries can directly affect two migration rates – the emigration rate and the return rate -- it is illuminating to estimate the research outcomes in settings with varying migration rates. We can reveal the policy effects then by comparing the outcomes with the real situation. The simulation results will not only demonstrate whether emigration of scientists makes the host countries more productive at the expenses of China, but also will show how the total output by Chinese scientists would change from a global perspective. The last research question is stated as follows:

Q4. Given different conditions in terms of migration rates, how would the scientific production change in China, the host countries, and the world?

Chapter 3 Data Collection

The complex nature of this study requires careful designs in sample coverage, identification strategy, data sources, and weighting method. This chapter introduces how we generated the final data set for answering the research questions and testing the hypotheses. The first section discusses the data used in previous studies and their inadequacies for the purpose of this research. The second section introduces the global coverage of the sample. The next two sections illustrate the identification process and survey procedure, followed by a discussion on data cleaning and the weighting method. The last section explains the matching process of bibliometric and demographic data.

3.1 Data collection in previous studies

Laudel (2003) argues that three conceptual and methodological problems need to be solved in an investigation of scientists' migration: "scientific specialties must be delineated, elite members must be identified, and the latter's spatial mobility must be observed". Section 3.2 and 3.3 will solve the first two problems, and here we only address the third. A comprehensive evaluation of skilled emigration requires cross-sectional data covering both domestic and overseas scientists, but common demographic information is insufficient to retrieve individual migration history. For example, we can identify an emigrant scientist easily if he was born in China and works in the US now.

However, we can not distinguish a stayer with little overseas experience from a returnee with a foreign degree, since both of them are Chinese and work at domestic universities. In order to distinguish their identity, it is also necessary to collect spatial and temporal indicators of past education and affiliations.

The overall impacts of skilled migrants can not be revealed even after we draw a clear picture of their migration trajectories. For example, one alarming report claims that India and China have dwarfed the United States in regards to the number of engineering graduates (NAS 2007); while it is found later that the Asian totals include many technical college graduates with short-term training, who can not match average American engineers in terms of skill level (Gereffi et al. 2006). In this regard, both quantitative and qualitative indicators are needed to estimate intellectual impacts of research personnel.

The idea of combining quantitative and qualitative indicators had emerged in the literature on scientific achievements one century ago. Cattell (1903) pointed out that "who's who" directories can be used as a source to collect data on men of science in a nation and their research performance. It is crucial to differentiate prominent scientists from mediocre ones in related statistics because the former not only make significant contributions to their disciplines, but also point new research directions out to their peers. Since research excellence has always been foremost for the competitiveness of national leading universities, Mahroum (1998) suggests that it is not only a question of quantity but the quality of flows that determine the impacts of skilled migration, with mobility of the most productive scientists having the strongest impacts.

The qualitative dimension is often missed in migration studies, however, as aggregated statistics assume implicitly that all skilled migrants are homogenous or similar in terms of skill level. The reality is the opposite. Individual research productivity ranges from no publication to highly cited works. The literature of social studies of science has documented large variations of researchers' performance for a long time (Lotka 1926). The distribution of research productivity generally follows or approximates Lotka's Law, which can be interpreted in the following plain words: "… most authors produce publications at a very low rate, few produce at the average rate and very few produce at twice the average (Huber 2001)."

Since research productivity of scientists appears highly skewed, formal credentials or years of education cannot provide much help in indentify their research level, and it is necessary to take into account the rankings of scientists' graduate schools and their publication records. Aided by these additional data, we can then map the composition of the domestic and overseas research workforce, and reveal the characteristics of different skilled flows as well as their implications.

Available sources provide only piecemeal data on skilled migration at the global level, to say nothing of scientific mobility. For example, two research teams generated large data sets of global skilled migrants based on national census data of both source and host countries (Carrington and Detragiache 1998; Beine, Docquier, and Rapoport 2007). However, their education variable are too aggregated (at the tertiary education level) to reveal the migration patterns of any particular profession. Micro data extracted from population censuses in both source and destination countries can generate a large numbers of observations, but they do not contain specific information needed for analysis;

nor can we trace international movements of scientists over time. Although nationwide surveys may interview returnee scientists, they seldom cover emigrants in major host countries, thereby making comparison impossible between migration groups. Constant and D'Agosto (2008), as one exception, used the "DA VINCI" database with 2,678 observations of Italian overseas scientists, but it does not address the qualitative dimension, either. A few studies adopted the database of the ISI highly-cited scientists[3], which covers global leading researchers in around twenty disciplines. Nonetheless, their samples either leave research performance aside (Ioannidis 2004; Weinberg 2011), or concentrate on migration flows between major host countries from a host country's perspective or a global perspective (Nerdrum and Sarpebakken 2006；Hunter et al. 2009). Laudel (2003) uses bibliometric databases to track authors' special mobility in a particular field, but she finds that the identification procedure is too time-consuming to process a large amount of data.

In order to cope with the above data limitations, social scientists have explored researchers' *curriculum vitae* (CVs) as a fertile data source for social study of science in recent years (Cañibano and Bozeman 2009). Since CV data provides detailed longitudinal information, they have opened up new possibilities for the study of research collaboration (Lee and Bozeman 2005; Lin and Bozeman, 2006; Fontes 2007; Jonkers and Tijssen 2008), career trajectories (Gaughan and Robin 2004), grant impacts (Gaughan and Bozeman 2002) and scientific mobility (Dietz and Bozeman 2005; Sandström 2009; Cañibano 2008).

[3] See the website at: http://isihighlycited.com/.

Almost every researcher is required to prepare a CV for conferences or grant applications. CVs contain relatively valid and reliable information, such as educational background, employment history, publications and other scholarly outputs, which are all useful for the study on migration of scientists. CVs record academic positions and accomplishments by relatively standard means, so it is not difficult to relate research performance with career path. Scientists sometimes post their CVs on their official/personal web pages, from which we can extract information without request.

Nonetheless, CVs as a data source bring several methodological problems, such as availability, comprehensiveness and codification (Dietz et al. 2000). Only a few researchers' CVs are available on the internet, and their distribution is probably not random, indicating that it is difficult to generate a representative sample based on CV data. Some of the aforementioned studies used CVs collected by a particular national research program or downloaded CVs from scientists' homepages. Their samples thus suffer from the problem of selection bias. Some important information for research analysis may be missing in CVs, or at least in some CVs. For example, in a recent study, only 211 out of 1,047 researchers mentioned their nationality explicitly in their CVs (Van Bouwel 2010). In addition, although a few countries have proposed to digitalize and standardize researchers' profile (e.g. EURO-CV 2009), most CVs are quite different in terms of structure and format, raising challenges to codification.

Compared with other approaches, a transnational survey via electronic means is probably the most appropriate and cost-effective method for the study of a scientific brain drain. A survey can collect necessary information and interview scientists randomly from different cohorts and regions, thereby generating a representative sample. This present study mainly relied on a survey to collect the biographical data, and also combined CV data and bibliometric data, so as to overcome the limitations of each data source aforementioned[4]. The survey method avoided common problems of CV data, such as content heterogeneity and high processing cost. We then used the CVs available on the Internet as a supplementary source to fill missing values and check reliability.

Additionally, this study also employed two data sources to generate qualitative indicators. It uses the 2009 Jiaotong World University Rankings as a rough proxy of education quality and academic environment. Although there are quality differences between departments in the same university, department rankings are usually consistent with university rankings, particularly when we aggregate them into broad categories. Following the suggestion of Sandström (2009) that a linkage between CV/survey data and bibliometric data provides a bridging methodological step, this study extracted individual productivity indicators from the expanded version of Science Citation Index (SCI), so as to measure the research output of the targeted scientists more accurately.

3.2 Sample coverage

The target populations of this study are Chinese scientists in four selected fields at global leading universities, who have generally achieved academic excellence in their country of residence, and even in the world. These leading scientists are not only an

[4] A similar complementary approach has been adopted by Coupé (2005), but it mainly extracted information from CVs, and only did a very short survey for collecting supplementary data.

essential part of the national research workforce, but also a group of interest for migration studies because of their high international mobility.

Chinese scientists teach and study at research universities, and they also work for specialized research institutes, government laboratories, and corporate research centers. Nonetheless, the sample is confined to university scientists for two reasons. The first reason lies in the fact that although public research institutes used to be the main driver of scientific advancement (Altbach 2009), the higher education sector in China has gradually enhanced its importance in the national research profile (Huang, Varum, and Gouveia 2006). For example, the share of university publications represented 82.5% of the total scientific publication in China in 2009 in terms of the number of SCI-indexed articles (ISTIC 2010). The second reason is related to data availability. In order to publicize its teachers' profile to prospective students, a university is more likely to provide a name list of their faculty members on its website than a public research institute. More importantly, several evaluation agencies have ranked global universities systematically, so we can use the rankings to examine the selectivity of scientists' movements, while indicators assessing public research institutes do not nearly match their sophistication by far.

Despite some methodological problems and critical reviews, the Academic Ranking of World Universities (ARWU) by Shanghai Jiaotong University has become a well recognized assessment of global higher education institutions (Liu and Cheng 2005). Its ranking indicators include major international awards (e.g. Nobel Prizes and Fields Medals), highly-cited scientists in selected fields, articles published in Nature and

Science, articles indexed by SCI or SSCI, and average research performance. Appendix I gives the detailed criteria and weights of ARWU, or the Jiaotong list.

In order to obtain a better coverage of the target population, we selected all the universities in mainland China and seven English speaking countries from the 501 universities on the 2009 Jiaotong list. The seven countries include major immigration countries, including the United States, United Kingdom, Canada, Australia, and New Zealand, as well as two city states, Singapore and Hong Kong[5]. The selection of these countries is primarily based on the considerations that they are the major destination countries of Chinese scientists (Figure 2, MOE 2005) and the global knowledge network is weighted towards English-language environments (Altbach 2002). The geographic coverage enhances the explanatory power of this study, since it looks beyond the American context and contains other host countries. Taiwan, Ireland, and Israel also belong to the English academia, but mainland-born scientists are far less likely to migrate to these countries due to their small size and political constraints. Exclusion of the three countries would cause little selection bias[6].

There are 18 universities in mainland China and 243 universities in the seven countries on the 2009 Jiaotong list. Almost half of them (48.3%) are ranked above 200, while the rest are in the range between 201 and 501 (Table 3.1). Nearly 60% of these

[5] The sovereignty of Hong Kong has been transfer from the United Kingdom to China in 1997. However, Hong Kong can be viewed as a "foreign country" outside mainland China, if we take its high autonomy and westernized academia into consideration.

[6] It is much more difficult to identify Chinese researchers residing in non-English countries, such as Japan, France and Germany, simple because I do not understand any foreign language except English. To my best knowledge, no previous survey specially covered Chinese scientists in non-English countries. I did a pilot study in 2008 and tried to identify some Chinese professors at several top universities in Japan and France. I found very few Chinese names after browsing the English version of their websites. Chinese academics in these countries probably represent only a small fraction of overseas Chinese scientists.

universities are located in the US, over 15% in the UK, around 7% in Australia and Canada, respectively. There are five universities in Hong Kong, five in New Zealand, and only two in Singapore. The 18 universities in mainland China represent 6.9% of all of the 261 institutions (Table 3.2). The median ranking of the universities in each country also varies as considerably as their shares. The median ranking of Chinese universities is at the bottom (450), while that of American universities is as high as 175.

Table 3.1 Frequency of identified universities by ranking

Ranking	*Frequency*	*Percentage (%)*	*Cumulative percentage (%)*
1-50	44	16.9	16.9
51-100	29	11.1	28
101-151	24	9.2	37.2
152-200	29	11.1	48.3
201-302	58	22.2	70.5
303-401	38	14.6	85.1
402-501	39	14.9	100
Total	261	100	

Source: the author's calculation based on IHE (2009).

This study only targets Chinese natural scientists, because the majority of overseas Chinese scholars study natural sciences. More than one thousand university professors originally from mainland China worked in the US by the mid 1990s according to one survey, and about 800 of them were affiliated with science or engineering departments (Wang 1997). Among students sent by the Chinese government or public institutions, almost four out of five studied natural sciences between 1978 and 2001 (Table 5, Zhang 2003). A comprehensive study covering all natural sciences is beyond the scope this dissertation. Instead, the sample confines the fields of investigation to four big disciplines:

mathematics, physics, chemistry, and biology[7]. Many more scientists belong to these fields relative to other small disciplines, such as geology, astronomy, or agronomy. Migration trends of Chinese scientists in the four fields arguably represent general migration patterns of academics between China and major destination countries. In addition, scientists of basic sciences are more likely to present their findings in the form of journal articles, instead of books or patents, than those of the social sciences or the applied natural sciences (Wanner, Lewis, and Gregorio 1981), which implies that we can measure the former's research productivity more accurately if journal articles are used as the only bibliometric data source.

Table 3.2 Frequency of identified universities by country

Country	*Frequency*	*Percentage (%)*	*Median ranking*
Australia	17	6.5	250
Canada	22	8.4	240
China	18	6.9	450
Hong Kong	5	1.9	250
New Zealand	5	1.9	350
Singapore	2	0.8	300
UK	40	15.3	240
USA	152	58.2	175
Total	261	100	250

Source: the author's calculation based on IHE (2009).

A key variable in the discussion of brain drain is age at emigration. A person's emigration does not result in a considerable human capital loss unless he received higher education or acquired professional skills in the home country. Those who migrated in their early ages, like the Taiwanese American Jerry Yang, the founder of Yahoo.com, are

[7] Nowadays "life sciences" more frequently refer to a variety of branches in biological studies from genetics to ecology. This paper uses the phrase interchangeably with the term "biology".

not typical skilled migrants in the discussion of brain drain. Hence a Chinese scientist in the target population is required to be born in mainland China and obtain his BS degree (Bachelor of Science) at a Chinese university. Those born in foreign countries with Chinese ethnic background, or later awarded BS degree by a foreign university, are excluded from the sample after completion of the survey.

3.3 Identification of scientists

It is a complex task to construct a sampling frame listing thousands of the targeted scientists, because no existing survey or census covers them comprehensively. We have to identify each scientist by a thorough online search. Since most university scientists are affiliated with a particular department or a research center, their identity information is probably accessible by visiting the websites of their affiliations. A team led by Paula Stephen and Baoyun Qiao first explored this data source in 2007 and they coded information on the web pages of the economics and biology departments at 45 leading Chinese universities (Freeman, Stephan, and Trumpbour 2008). Welch and Zhang (2008) also compiled a list of mainlander academics by checking Chinese names on Australian university websites.

The procedure of identification in this study results from three search steps at the university, departmental, and individual level, respectively. As a cost-effective strategy in the first step, we selected 120 universities systematically from the 234 institutions in five

English countries on the ranking list[8], because it is too time-consuming to conduct a census covering all the foreign institutions. All of the seven universities in Hong Kong and Singapore were selected, as well as the eighteen ones in mainland China. We then visited the websites of 522 departments[9] at the 145 selected universities by searching related key words[10] and reading the web pages of their faculty members[11] carefully to identify each Chinese name (Table 3.3).

Table 3.3 Frequency of identified universities, departments, and population

Region	*University*	*Department*	*Target population*	*Identified Scientists*
English countries	120	426	1328[1]	664
Hong Kong and Singapore	7	26	298	146
China	18	70	5556	2778
Total	145	522	7182	3588

Note: This figure is estimated by doubling the 664 identified scientists in the five English countries.

The four fields of the target population, mathematics, physics, chemistry and biology, do not always match their corresponding departments at a university. Quite a few universities do not have programs in all of the four fields, and some small institutions have merged mathematics, physics, and chemistry into a "school of science". Several medical universities offer no program in the four fields. The four are occasionally mixed with other disciplines. For example, some departments combine physics with astronomy

[8] The five English countries are the UK, the USA, Canada, Australia, and New Zealand.
[9] Some research units use "school" in their names and they are treated as departments.
[10] For example, we can find the website address of the Mathematics Department at Harvard University by searching "Harvard" and "math" together with Google.
[11] Most of the departments provide the profile of their faculty members under the column "people" or "research" of their websites.

or engineering, and others have merged biochemistry and environment science. We simply ignored Chinese scientists of other disciplines in such cases. Another selection issue is that some universities have two or three biological departments, each of which focuses on a specific subfield. For simplicity, we only checked one of the biological departments, usually that of cell or molecular biology, instead of ecology, botany, zoology or evolutionary biology, which tend to have a marginal status in life sciences[12]. Every Chinese university has established departments in the four fields. Many of these departments have changed their names as "schools" thanks to their rapid expansion in recent years, and they have many more faculty members than typical foreign departments[13].

The identification procedure bifurcated at the individual level. We identified every Chinese scientist in the five English countries, since a stratified sampling was already conducted at the university level according to their rankings. With regard to mainland China, Hong Kong and Singapore, where the local academia largely consists of Chinese, we compiled a name list of mainlanders firstly based on the information on the department websites[14]. There are 5556 scientists in China and 298 in the two city states on the list, and we selected half of them systematically for identification. We identified 3588 scientists in total finally (see the last column in Table 3.3), and recorded the name,

[12] A Chinese professor at Chicago told me in his email that Chinese biologists in the U.S. tend to concentrate in experimental research areas, with only a few in theoretical ones.

[13] Three websites of the Chinese departments are found inaccessible: the school of science at China Agriculture University, the school of mathematics at Dalian University of Technology, and the school of science at Harbin Institute of Technology. In addition, the University of Science and Technology of China has two departments of chemistry, both of which are included in the sampling frame.

[14] The names of a few scientists appear on the websites of two departments at one university or even at two universities, which are caused by dual affiliation or recent job changes. These overlaps were identified and removed.

email address, CV availability, and official/personal web pages of each scientist.

Two criteria of identification need more explanation. For the purpose of consistency, we only identified Chinese scientists with a title of lecturer, reader, researcher, or professor of different types, and excluded research assistants, post doctorates, and doctoral students, though they are also part of the research workforce in their countries of residence. The adoption of this selection criterion is based on the consideration that the names and contacts of low-ranked scientists are often missing on the university websites, while information about professors and researchers are generally obtainable. In addition, we also ignored or excluded engineers, experimentalists, technicians, and those affiliated with teaching centers, because they do not conduct research necessarily, or they merely assist research.

The second criterion deals with the recognition of Chinese names. Most overseas Chinese with mainland background use the Pinyin pronunciation system to spell their names in English, which is the official system to transcribe Chinese characters in Mandarin Chinese. It is not difficult to distinguish such Chinese names from other ethnic names, and even from names of Taiwanese and Hong Kong people, because the Pinyin system is different obviously from that used in Taiwan or Hong Kong. Take the author's personal name as an example. My name is spelled as "*Fangmeng Tian*" in mainland China, "*Fongmang Tin*" in Hong Kong, "*Fan-mong Tien*" in Taiwan. Only a few Chinese immigrants use "mixed" names like "*Tim Tian*", which makes it difficult to distinguish them from ethnic Chinese born abroad. We ignored mixed names on the web pages of foreign departments in the identification process, unless the birthplace or college of scientists with such names can be confirmed to be located in China. Scientists in mainland China are easy to identify because the department websites provide their names in Chinese characters[15].

The department of computer science at George Mason University is used here for illustrative purpose[16]. There are eight Chinese names on the list of its faculty members, and four use the Pinyin system (Table 3.4). Among the remaining four, Jyh-Ming Lien and Jessica Lin are found to be Taiwanese according to their official web pages. Pearl Wang's background is unclear, and she is probably a Chinese American. Jim X Chen is the only mainlander who uses a mixed name, and his CV reveals that he received undergraduate education at Southwest Jiaotong University in China. All of the five Chinese mainlanders have personal web pages and email addresses. Two of them provide some biographic information with short or long CVs. Two other Chinese offer a brief introduction of themselves online, and only one person does not present any background information. Overall, checking Pinyin names seem to be an effective method of identifying scientists from mainland China.

Table 3.4 Chinese scientists at the department of computer science at GMU

Name	***Email***	***CV***	***Webpage***
Songqing Chen	sqchen@cs.gmu.edu	S	http://cs.gmu.edu/~sqchen/
Fei Li	lifei@cs.gmu.edu	B	http://cs.gmu.edu/~lifei/
Xinyuan Wang	xwangc@cs.gmu.edu	N	http://cs.gmu.edu/~xwangc/
Yutao Zhong	yzhong@cs.gmu.edu	B	http://cs.gmu.edu/~yzhong/
Jim X Chen	jchen@cs.gmu.edu	L	http://www.cs.gmu.edu/~jchen

Note: Column "CV": L – long CV; S – Short CV; B – brief bio; N – no CV/bio info available.

[15] We found only four foreign scientists teaching at Chinese universities, and they were excluded from the sampling frame.
[16] See the web page of its faculty members at http://cs.gmu.edu/faculty/, visited on Jun. 5, 2011.

3.4 Survey and effective observations

We identified nearly 3600 scientists and obtained their basic information by reading the departmental web pages. Over 2400 of them were invited to join the survey, because the email addresses of the rest are not available on their web pages. Roughly one third of the domestic scientists' email addresses are missing either because the information on their web pages is incomplete or because the websites of their departments are under construction. By contrast, only fourteen overseas scientists' email addresses are missing. Overall, there are 1639 domestic scientists and 796 overseas scientists on the name list for survey (Table 3.5). Scientists at less prestigious universities in China are under represented in the sample compared with those at prestigious universities, because the former's email addresses are more likely to be missing. We corrected this selection bias later by a weighting scheme (see Section 3.5).

Table 3.5 Frequency of survey population and response rate by group

Group	*Identified scientists*	*Name list*	*Effective response*	*Response rate (%)*
Domestic scientists	2778	1639	360	24.4
Overseas scientists	810	796	139	19.4
Total	3588	2435	499	22.8

Note: The response rate is calculated based on the assumption that 10% of the email addresses are false, invalid, or seldom checked by their owners.

We conducted the survey in two waves. The first wave was conducted in late August, 2010. We sent an invitation letter to two thirds of the scientists on the name list on an individual base. Each recipient was addressed personally with his last name, so as to increase the response rate. The letter asked the respondents to fill out an online questionnaire[17]. We sent a reminder letter individually to those who had not filled it out one week later, as well as another reminder letter by one group email to all the non-respondents two weeks later. The number of effective responses collected in the first wave is acceptable but lower than a satisfactory level, so we launched another wave of survey in late October, 2010. The second wave repeated each procedure of the first.

Nearly six hundred respondents returned effective questionnaires after the two waves of the survey. If we assume 10% of the email addresses are false, invalid, or seldom checked by their owners, the overall response rate reaches 22.8% (Table 3.5), which is close to that of some previous studies (Constant and D'Agosto 2008) and lower than others (Nerdrum and Sarpebakken 2006). The response rate of the domestic scientists (24.4%) is slightly higher than that of their overseas colleagues (19.4%), possibly because the former were more motivated than the latter by the invitation letter, which stressed the importance of the survey in evaluating the research workforce in China.

We established the online questionnaire at a professional survey website "Survey Monkey"[18] and revised the questionnaire after a pretest in the summer in 2010, which collected eighteen responses from the sixty recipients of the survey request. The final questionnaire has two types run in parallel, with one directed to domestic respondents and

[17] The invitation letter mentioned that Center for China and Globalization of the Western Returned Scholars Association supported (WRSA-CCG) the project and the online questionnaire used the logo of WRSA on its web pages, which might be helpful for improving the response rate, since people are more likely to cooperate with survey investigators with organizational background.

[18] Survey Monkey is a private American company that enables users to create their own Web-based surveys. See their website at: http://www.surveymonkey.com

the other to overseas respondents. Only certain several questions about education background and visa status are different in the two. In addition, the respondents could choose to read the questionnaire in either Chinese or English. Over 95% of the domestic respondents chose to fill the Chinese version, while less than two thirds of the overseas scientists did so. The bi-linguistic approach probably helped raise the response rate of overseas scientists, because some respondents in foreign countries had difficulty in reading Chinese on their computer screens.

The questionnaire uses two kinds of instruments to elicit information (see Chapter 4 and Appendix II for details). The first kind is multiple choice questions, and a respondent can make a choice with one mouse click. The second one is blank spaces. A respondent is asked to fill a name or figure related to his background. There is no open-ended question in the questionnaire. The survey items are divided into five modules dealing with different aspects of the backgrounds of Chinese scientists: personal characteristics, educational background, current research positions, past working experience, and international mobility. The cross-sectional survey provides a clear picture of the career paths of Chinese scientists at different stages through retrospective questions.

Not all of the five hundred respondents are qualified observations for generating the final data set. China reestablished the national entrance examination system and adopted the open-door policy after 1978, which helped push the first wave of overseas students in the past three decades. Some old respondents received their college education before or during the Cultural Revolution. We exclude them from the final sample, because they did not have opportunities for overseas study after graduation and the quality of their tertiary education is difficult to assess. A few young scientists obtained their doctoral degree after 2007, and they were not supposed to publish in 2006, since they were still studying in their doctoral programs at that time. Hence these respondents were also excluded. The too-old and too-young group represents around 11% of the effective responses, so the sample size is reduced to 445 observations after the exclusion.

It was almost impossible to match the survey data of 32 respondents with their publication records due to identification problems (see Section 3.6 for details), and they had to be deleted from the sample. As a remedy, we incorporated the eighteen responses collected from the pretest to expand the sample size. We also acquired some supplementary information on eight respondents who did not complete the survey by reading and codifying their CVs available online. The second reminder letter asked non-respondents to forward their CV to us if they were reluctant to fill the questionnaire, and fifteen scientists sent their CVs after the request. We extracted personal information from twelve of these CVs and added them to the sample. These additional observations expand the sample size by nearly 10%, and the total number of observations reaches 451. The added individual scientists have diverse backgrounds, so they probably bring little selection bias to the sample.

3.5 Data cleaning and weighting method

Data cleaning is a necessary procedure to ensure the data quality. There are random false information and systematic bias in the raw data, so we made quality check at both micro level and macro level.

Over four fifths of the scientists in the sample provide some useful information on their web pages, which ranges from a simple description of research interests to a long CV recording every conference presentation. We checked the validity of the survey data by comparing them with the relevant information on the web pages. Around one out of five respondents were found to report inaccurate or wrong information, and we corrected these recall mistakes according to their CVs, since the latter is a more reliable source. A significant number of respondents did not answer certain questions, such as their gender or length of overseas experience. We replaced a majority of the missing values with information elicited from their web pages. For example, the gender of a domestic scientist can possibly be recognized from his or her Chinese name; and an overseas scientist's gender can be determined by his or her photo. These checking methods reduced the risks of measurement errors considerably.

The representativeness of the final data set also requires careful assessment. The sampling frame probably misses a number of new faculty members, because some departments might not have updated their rosters. In addition, several Chinese departmental websites do not provide the profile of their assistant professors and lecturers. The omission of these two groups does not result in considerable selection bias, since the sample only covers those who obtained their highest degree by 2007. These scientists would have probably been promoted to associate professorship by 2010, and established their web pages on the websites of their affiliations.

The major selection bias results from non-responses, which do not occur randomly.

Higher response rates usually, if not always, imply higher representativeness, so the OECD doctorate survey proposal recommends that the sample fraction (ratio of the sample size to the population size) should exceed 20% (Auriol, Felix, and Schaaper 2010). Because the sample frame of this study only covers one out of three in the target population, its sample fraction is only 7.4%, or one third of the overall response rate (22.8%), which indicates that the non-respondents might differ from the respondents by key individual attributes.

A weighting method can improve the representativeness if there is an appropriate reference population for comparison. However, we can not extract such a population from existing data sources. For example, the US census micro data cover Chinese S&E workers but do not provide important information used in this study, such as discipline or ranking of affiliation. In addition, Chinese scientists in other English-speaking countries might differ considerably from their counterparts in the US. Simon and Cao (2009) depict the demographic profile of China's S&T talent pool, but the big picture does not focus on the elite scientists at leading universities. We have to use the sampling frame to calculate the weights.

The sampling frame offers three key variables – location, field, and university ranking. Because of the email availability, less than the two thirds of the domestic scientists received the invitation letters, while almost all overseas scientists did, indicating the latter were over sampled. Hence we divide the sample into two parts by location (the domestic part and the overseas part), and weighted each part separately. The two parts were categorized into twelve and eight cells by field and university ranking, respectively. So were the two corresponding parts of the sampling frame. The frequency weights were generated as the ratio of a cell's frequency of the sample to that of the sampling frame. We then assigned the weights to the observations according to their cells after modifying several extra large weights. It should be noted that this weighting scheme has adjusted the disciplinary and ranking distributions of the sample, but it does not address the non-response bias in terms of other variables, such as age or professional status.

3.6 Bibliometric data

This study drew publication data from the expanded version of the Science Citation Index (SCIE) produced by Thomson Reuters[19], which is the most frequently used database in bibliometric studies. The SCIE covers about 9500 international peer-reviewed journals in 2009 (Moed 2009). It includes cited references from each source article and authors of a source article, as well as their affiliations. Its coverage tends to be excellent in physics, chemistry, and biological sciences (Moed 2009), which are three of the four fields covered by this study[20].

As Tyfield, Zhu, and Cao (2009) point out, the SCIE database underestimates Chinese scientists' total research output considerably, because it does not include a majority of Chinese journals. However, Chinese scientists at top national universities are much more active in English academia than average domestic scientists, and published

[19] See the website at http://apps.isiknowledge.com
[20] Some studies use another large database "Scopus" as the data source (e.g. Gaule 2011), whose coverage is mostly overlapped with the SCIE.

most of their works, or at least those of the highest quality, in SCI-indexed journals, since publications on these journals can bring both intellectual and material rewards to them (Jia 2005). Publications in Chinese journals are generally viewed as inferior to those in international journals[21], and even citations in Chinese journals are more likely to refer to international sources instead of domestic ones (Zhou and Leydesdorff 2007). Since the omission of articles published in Chinese journals would not cause a substantial error of measurement, this study does not collect bibliometric data from Chinese sources, such as the Chinese Scientometric Indicators or the Chinese Science Citation Database (Jin et al. 2002).

Using the "author finder" tool provided by the online interface of the SCIE, we searched each author's publications by matching his name, field, and affiliation in the three observation years, in order to identify the same individual unambiguously. Following a common practice among bibilometricians (Jonkers 2010, Section 2.5), we recorded the information of research articles, reviews, notes, and letters; conference proceedings and meeting abstracts were ignored because they are not peer-reviewed documents[22]. We thus generated a set of indicators of the publications by the 451 scientists in the sample (see Section 4.1).

A Chinese scientist at a foreign university is relatively easy to identify in the SCIE, because he is probably the only person, or one among several Chinese, who uses a particular Chinese sir name. The SCIE database presents only the initial letters of an

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[21] This observation was confirmed by several domestic scientists I interviewed in summer, 2008.

[22] There are thousands occurrences in the three observation years including a few of double counting because of coauthoership.

author' given name before 2006, which makes it difficult to identify domestic scientists, particularly when they share similar names and work in the same department. For instance, there are two scientists in the school of physics at Peking University. The one's name is "Qing Zhao", and the other's is "Qiang Zhao". Their names recorded by the SCIE are exactly the same (Q. Zhao). The search tool "author finder" only allows identification at university level and offers just five disciplinary options[23], thereby further complicating the search process. As a solution, we often resorted to the publication titles listed in a scientist's CV or on his web page to verify the SCI records[24]. Nonetheless, 32 observations had to be dropped from the original sample in extreme cases, as it was impossible to match their identity with the bibliometric data.

Not all of the scientists are supposed to have publication records in every observation year. A scientist is supposed to publish from the penultimate year before the completion of his doctoral program, though he might have published even earlier. For example, we recorded a scientist's indicators of productivity from 1998 if he was awarded the highest degree by 1999. One's publication records were checked in 2002 and 2006 if he graduated in 2003, so do those who graduated between 2000 and 2002. As a result, 250 scientists have publication records in 1998, 353 have records in 2002, and all (451) have records in 2006.

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[23] The five fields are arts and humanities, life sciences and biomedicine, multidisciplinary science and technology, physical science, and social sciences. Only three can be used for identification since the study does not cover the first and last field.

[24] Over half of the scientists provide a partial or full coverage of their publications on their web pages. They are more likely to exhibit recent publications than old ones.

Chapter 4 Variables and Measurement

After the collection of the raw data, it is necessary to transfer the survey items into variables and codify each variable according to the specific needs of later analysis. The first section of this chapter introduces the bibliometric variables and discusses the validity of the constructed indicators of research productivity. The second section describes several geographic variables, including those related to locations and migration history. The last section presents a group of demographic variables with a summary of their descriptive statistics[25].

4.1 Bibliometric variables

Measurement is probably the most important technical issue in studies of scientific productivity. Reliable measurement of research output is essential for answering three of the four research questions presented in Section 2.3. Since it is difficult to measure the contribution of a research article, an ideal assessment of its quality requires peer review by a group of experts. However, it is both time-consuming and expensive to evaluate a large number of publications by a process of peer review. Instead, bibliometricians suggest that a group of indicators can proxy different facets of research output (Martin 1996). This study uses eight indicators as proxies of research productivity, research

[25] Some variables of less importance are not presented in this chapter, because analyses related to them are not presented in this dissertation.

performance and international collaboration, whose definitions are given in Table 4.1.

Table 4.1 Name and definition of the bibliometric variables

Name	***Variable***	***Definition***
totpap	Total number of papers	Annual fractionalized number of SCI papers
totcit	Total citation counts	Fractionalized citation counts received in a three-year window
output	Total research output	Annual fractionalized number of SCI papers weighted by a parameter plus the citation counts
highperi	Highest individual performance	Citation counts of a scientist's single most cited paper in an observation year after adjusting the number of authors
highpert	Highest team performance	Citation counts of a scientist's single most cited paper without adjusting the number of authors
intercol	International collaboration	Whether a domestic scientist coauthored internationally
cncoll	Collaboration with overseas Chinese	Whether a domestic scientist ever coauthored a paper only with overseas Chinese
chicoll	Collaboration with China	Whether an overseas scientist coauthored with scientists in China

The number of publications in peer-reviewed journals is frequently used as a simple measurement, and the first bibliometric variable "*totpap*" indicates the number of SCI publications of a researcher in an observation year. Since it is almost impossible to single out each author's contribution in a coauthored paper, the values of this variable are calculated by adjusting according to the number of authors of each paper and summing up one's fractionalized publications, under the assumption that each author deserves equal credit. Suppose a Chinese scientist is one of the four authors of a paper. He gets only one quarter of a point for his contribution to the paper. Some scholars have proposed an alternative weighting method, which assigns weight to each author according to his position in the name list of a paper (Abbas 2011). An author is assumed to have the largest contributions if his name is first in the list. Despite of its sophistication, this method is not practical in processing a large amount of bibliometric data, because there is no consistency in how names are listed. Some order names according to individual contribution, while others do so alphabetically.

The number of publications is a partial indicator of scientific production, as it does not distinguish a prominent scientist who makes a major contribution from those who make only modest contributions, when they publish the same number of papers in a given period. Some students of research productivity use journal impact factor to weight publications, as they assume that papers in journals with higher impact factor are of higher quality (e.g. Gaule 2011). This method is often criticized by bibliometricians because a journal's impact factor is determined by the number of citations received by the papers in it, not vice versa. Sometimes the most cited half of articles in a journal are cited ten times as frequently as the least cited half (Seglen 1997).

We decided to assign weights to publications according to their citation counts in a three-year window after its publication, since the use of journal impact factors conceals the difference between articles in the same journal. The construction of the second variable "*totcit*" is similar to the first one, and we replaced the fractionalized number of each paper with that of citations received by each paper. In other words, each paper is weighed by its citations. Since there is a lag between the publication of an article and the publication of the articles that cite it, the number of citations can be counted only after a sufficient amount of time. The three-year window is viewed as the minimally sufficient amount of time for reliable bibliometric analyses (Glänzel, Thijs, and Schlemmer 2004). Similar methods are sometimes used to evaluate academic institutions or individuals. For example, Ben-David (2010) ranks economists and departments of economics in Israel according to the sum of the fractionalized citation counts of their publications.

The variable *totcit* is not only treated as a measure of research impact in this study, but also viewed as a rough approximation of the relative quality of research. Research impact in terms of citation is not equal to research quality, because a paper can be cited for a variety of reasons irrelevant to its quality[26]. Scientists are seldom consistent in their referencing practice, so the quality of a paper is not necessarily in accordance with the citations it receives. One famous example is the 'halo effect' (Martin 1996), as a prominent researcher's reputation improves the chance of citing his work by others considerably. Using ecological literature as the data source, Leimu and Koricheva (2005) find that the annual citation rates are affected by article length, the number of authors, and their affiliations. Other factors, such as the number of the references and document type, are also found to influence citation frequency of publications (Bornmann et al. 2008). These "noisy" effects weaken the validity of using citation counts as an unbiased indicator of research quality.

Nonetheless, many studies have confirmed that the number of citations in the SCI-indexed journals is a statistically valid measure of research quality. It is hard to define the real meaning of the "quality" of research. Martin and Irvine (1983) stated that "(research

[26] Some bibliometricians even argue from a constructivist perspective that citation does not necessarily represent true influence of one's work (Macroberts and Macroberts 1996), and it can not be used as impact indicators.

quality) is a property of the publication and the research described in it. It describes how well the research has been done, whether it is free from obvious 'error', how aesthetically pleasing the mathematical formulations are, how original the conclusions are, and so on." This definition looks incomplete, and research quality might be recognized only by peers in the same discipline. As the number of citations is closely associated with peer opinion, bibliometricians prefer to use it as an acceptable proxy of research quality. Narin (1976) finds that high citation rates correlate with positive peer opinions of research articles and with other quality indicators. Aksnes (2006) supports the idea that citation counts have the highest accuracy in identifying different contributions and shows that the number of citations corresponds reasonably well with the authors' own assessments of their contributions. A small-scale survey targeting top Dutch scientists confirms that highly cited papers in the international journals are valid proxies of excellent academic performance at aggregate levels, since the large random variations are averaged out (Tijssen, Visser, and Leeuwen 2002). For example, Nobel laureates often receive an order of magnitude more citations than their peers in the same discipline before they were awarded the prize (Garfield 1992). Since most analyses in this study are conducted at aggregate levels, citation counts can roughly indicate research quality, particularly when the difference in the number of citation rates is substantial[27].

[27] Two additional technical issues related to the citation variable need to be addressed: review papers and self-citation. Review articles are generally cited more frequently than other publication types (MacRoberts and MacRoberts 1996; Aksnes 2006). It is debatable whether it is "over cited", because the contribution of a review paper is not always comparable with a research paper. Since scientists in the sample seldom published review papers in the observation years, this issue ignorable from our perspective. With regard to self-citation, it is an essential part of scientific communication, and its trajectories are not statistically different from citations by other scientists (Glänzel, Thijs, and Schlemmer 2004). Hence this study gives equal points to self-citations as to other citations.

Quantity is no substitute for quality, and vice versa. We can answer the second empirical question in quantitative and qualitative dimension now, as the variable *totpap* and *totcit* provide information in both regards. For example, returnee scientists, on average, might produce a similar number of papers as those who remained in China on average, but the former were more productive than the latter in terms of citation counts. However, we still need a single variable of research productivity for simulation, which incorporates both dimensions. The third variable "*output*" in Table 4.1 is constructed to be a proxy of individual research productivity, or research output in an observation year. The research output of a scientist is calculated as the number of citations he received plus the number of publications multiplied by a factor of *p*. Its mathematical definition is given by the following formula: *output* = *p* * *totpap* + *totcit*.

This definition is based on the rationale that a research paper should be given certain credit besides its citations. The question is how much credit a paper deserves, or how to determine the *p* value. The median of *totcit* was 1.6 in 2006, while the median of *totpap* was 0.5, indicating a paper written by an average scientist received 3.2 citations (1.6/0.5) on average. If we assume the quality of a paper with no citation is equal to one third of that of a paper by an average scientist, then the former gets 1.6 points, while the latter gets 4.8 points (1.6+3.2). In other words, a paper should get 1.6 points in addition to its citations in 2006. Since the papers by the Chinese scientists received fewer citations on average in 2002, and even fewer in 1998, the value of the parameter *p* is adjusted to 1.2 and 0.8 for 2002 and 1998, respectively.

For the purpose of illustration, suppose Prof. John Smith, a biologist at George

Mason University, is the single author of paper X and one of the three authors of paper Y. Both paper X and Y were published in 2006 and they were cited by 4 times and 9 times in the following three years, respectively. Prof. Smith's research output is calculated as

output = (1+1/3) * 1.6 + (4 + 9/3) = 7.1

One caveat of interpretation needs to be mentioned here. The values of the variable *output* should be interpreted with caution, though it quantifies individual productivity better than either *totpap* or to*tcit.* If scientist A's value of *output* is 50 points and B's value is 25, we can not tell that A's productivity is exactly as twice as B's. However, it is fair to say that A's productivity is higher than B's, or substantially higher than B's. The indicator *output* is more like an ordinal variable in this sense, but its quantitative nature largely simplifies the data analysis[28].

Someone may ask why this study did not adopt the H-index, since it is a new and popular indicator of research performance (Hirsch 2005). Although the H-index has many advantages over other bibliometric measures and incorporates both quantity and quality of publications (Bornmann and Daniel 2007), it becomes insensitive to a small number of papers or a group of lowly cited papers. It is strongly biased towards highly productive researchers with many more and much better publications than those with average records (Moed 2009). Considering these drawbacks of H-index, we used the more

[28] In addition, observation in a single year might result in certain selection bias, because a scientist might publish his findings in a short period after hard working in his laboratory for several years, or publish nothing after a sabbatical year. His research output would be overestimated in the former case, and underestimated in the latter one. The validity of the index output could be improved if we expand the observation period to two consecutive years, but it would double the workload of bibliometric data collection. In addition, the selection bias caused by a single-year observation is not very serious, because we find individual research output in adjacent years is similar to the observation year, and the occasional fluctuations can be averaged out at aggregated level.

reliable *output* instead.

Papers of higher quality, thereby attracting more citations, are arguably more representative of cutting-edge science than average papers. The difference between radical and gradual discovery is sometimes not only one of degree, but also one of kind. Highly cited papers often introduce new notions, methods, or novel approaches to the routine practices in "normal sciences" from a Kuhnian perspective, and expand the horizon of peer researchers. For instance, a research paper cited 100 times in a discipline is probably more valuable than 10 papers with each cited 10 times.

In order to reveal the intellectual impacts of skilled emigration, it is necessary to further examine the qualitative dimension of publications. Tijssen, Visser, and Leeuwen (2002) identify world-class research institutions by focusing on the top 1% papers with highest citations, since the average citation scores of these institutions is an inadequate predictor of their production of high quality papers. This rationale also applies at the individual level. The citation counts of the most cited paper of a scientist, or "*highperi*" for short, is constructed to indicate the highest individual performance. For example, if one receives ten citations for his single most cited paper after adjusting the number of authors, his highest performance is coded as ten, no matter how many papers he published in the observation year. Since only a small number of papers in the sample are authored by a single person, this indicator without adjusting the number of authors measures the highest performance of the research team one participated in, and it is named "*highpert*" as the fifth bibliometric indicator.

Scientific communication can take many forms, and most science studies concentrate on the formal aspect of international collaboration, because informal collaboration is difficult to measure. As journal publications are viewed as the major channel of formal communication in science (Moed 2002), coauthored publications remains one of the most reliable and well documented indicators of research collaboration (Katz and Martin 1997). The last three indicators measure international collaboration status of Chinese scientists from the perspectives of different groups. We can learn about the contribution of the Chinese scientific diaspora to China by examining the association between these variables and the productivity level of domestic scientists.

The first two indicators, "*intercol*" and "*cncoll*", only apply to domestic scientists. A paper by a domestic scientist is referred to as internationally coauthored if the addresses of the authors' affiliations contain at least one foreign country. The binary indicator "*intercol*" is coded as "1" if a domestic scientist's coauthored as least one paper with foreign authors, and "0" if not. We can not match one's collaborators and their countries of residence, because the SCI database does not attribute affiliations to individual scientists. However, a paper can be identified as coauthored with overseas Chinese mainlanders, when all the authors from different countries use the pinyin system to spell their names. The indicator "*cncoll*" is thereby constructed to show whether a domestic scientist had collaborated only with overseas Chinese (coded as "1") or not (coded as "0"). Similarly, the variable "*chicoll*" shows whether an overseas scientist had collaborated with scientists in China in a given year.

The first five bibliometric indicators in Table 4.1 quantify the publications of each scientist in the sample, which help us answer the second question and test the fourth hypothesis. The remaining three indicators allow us to test the fifth hypothesis by identifying the collaboration status of each individual. Table 4.2 presents some descriptive statistics of these variables in 2006[29].

Table 4.2 Major statistics of the bibliometric indicators in 2006

Name	*Median*	*Mean*	*SD*	*Minimum*	*Maximum*	*Observation*
totpap	0.5	0.82	1.14	0	7.97	451
totcit	1.6	5.71	12.44	0	120.3	451
output	3	7.05	13.74	0	125	451
highperi	1.13	2.57	4.85	0	64	451
highpert	4	10.11	15.82	0	128	451
intercol	0	0.27	0.44	0	1	264
cncoll	0	0.13	0.34	0	1	264
chicoll	0	0.20	0.40	0	1	187

Note: SD refers to standard deviation.

4.2 Geographic variables

The survey asked the Chinese scientists for their retrospective life histories, such as working affiliations, university education, as well as duration overseas. We then used these temporal and spatial variables to calculate the migration status of each individual in every observation year. This section enumerates major geographic variables with a brief introduction.

Location of highest degree (phdloc) [30]. According to the university where one received his highest degree, we assigned a code to this variable by geographic location. This variable has three values: mainland China, the United States, and the rest of the

[29] These statistics have been weighted except the number of their observations.
[30] The abbreviation in the paraphrases is the short name of the variable, and the same below.

world (ROW). Due to the small sample sizes, the remaining countries are grouped into the ROW, which mainly covers the English-speaking countries, as well as Japan and some European countries.

Location (loc): These three variables are similar to the previous one. They indicate the location of one's working affiliation (China/ US/ROW) in the three observation years. We also transfer them into three binary variables with "0" for "in China (domestic)" and "1" for "outside China (overseas)". These location variables are useful for observing the international migration flows of graduates from a particular region.

Overseas duration (duration). The survey asked those respondents who had obtained their highest degrees how long they stayed overseas for study or work by 2006. For example, a visiting scholar might spend one year abroad, a returnee with an American degree might stay in the US for six years, while a permanent resident in Hong Kong might have stayed there for over ten years. This variable does not apply to eighteen scientists who obtained their highest degree after 2006, as they had not finished their graduate education by then.

Short mobility status (shortmob). The mobility experience of scientists is dynamic and affected by length (short or long term) and direction (between China and a foreign country). To learn more about the mobility patterns of Chinese scientists between 1998 and 2006, we designed three questions in the survey to solicit relevant information. The first two questions focus on one's mobility status during the two short periods (1998 – 2002 and 2002 – 2006). The survey asked those who graduated before July 2002 to choose one option which best describes their mobility history between July 1998 and

June 2002 (Table 4.3), so are those who graduated before July 2006 for their history between July 2002 and June 2006. For example, one's mobility status is coded as "1", if China was his residence at the beginning of the four-year period, and his overseas duration was less than nine months during the period.

Table 4.3 Mobility history during the two four-year periods (1998-2002, 2002-2006)

Code	***Primary residence***	***Direction of mobility***	***Length of duration by location***	
			China	***Overseas***
1	China	China to overseas		Less than 9 months
2	China	China to overseas		More than 9 months but less than 2 years
3	China	China to overseas		More than 2 years
4	Overseas	Overseas to China	More than 2 years	
5	Overseas	Overseas to China	More than 9 months but less than 2 years	
6	Overseas	Overseas to China	Less than 9 months	

Note: See Question Q33 in Appendix II for the plain text of the questions.

Table 4.4 Mobility history during the eight-year period (1998-2006)

Code	***Primary mobility type***	***Direction of mobility***	***Definition***
1	Stay	China to overseas	overseas duration less than 2 years
2	Stay	China to overseas	overseas duration over 2 years
3	Return	Overseas to China	returned to China for full-time employment before July 2002
4	Return	Overseas to China	returned to China for full-time employment after July 2002
5	Emigration	Overseas to China	academic experience in China less than 1 year
6	Emigration	Overseas to China	academic experience in China over 1 year

Long mobility status (longmob). The third question identifies the relatively long-term mobility status of Chinese scientists between 1998 and 2006.The survey asked those who graduated by 2006 to choose one from six options, which best describes their mobility experience between 1998 and 2006 (Table 4.4). The six options were designed according to the primary mobility type – stay, return, or emigration during the observation period. For instance, one's mobility status is coded as "4" if he returned from the host country to China for full-time employment after July 2002. The mobility dynamics in reality are far more complicated than the typology presented here, but the aggregation of the large variations is necessary to present stylized facts.

Migration status (migsta). This variable has three broad categories: stayers, emigrants, and returnees. Stayers are defined as those who obtained their highest degree in China and stayed overseas for no more than two years by a given year, while emigrants are defined as those who worked for at foreign institution in the given year. Emigrants are further divided into two parts those in the US and those in the ROW for specific needs of analysis. There are two definitions of returnees. The narrow definition confines returnees to foreign degree holders at Chinese universities, while the broad one covers all the domestic scholars with at least two years of overseas experience (see Chapter 5.1 for details).

It is essential to distinguish the identity of each scientist in the first place, in order to estimate their impacts on China's scientific production. The above geographic variables can help us identify the migration status of each scientist in the three observation years. It is relatively easy to identify emigrants and returnees by the narrow definition, as we know the locations of their graduate programs and working affiliations. Identification of stayers and returnees broadly defined is more complicated, since there is no direct information of their overseas duration by 1998 or 2002. We predicted their identity based on their information of mobility status and overseas duration. For example, a domestic scientist was probably a visiting scholar in foreign countries before 2002, if he had stayed abroad cumulatively for five years by 2006, and his overseas duration between 2002 and 2006 was less than two years. Hence he should be coded as a returnee in 2002. We deduced most values of the variable *migsta* by this method, though some cases are unavoidably arbitrary.

Most of the geographic variables are categorical. The weighted descriptive statistics of some variables are given in Table 4.5. The statistics of mobility and migration status are not presented here, because Chapter 5 will analyze the related information in detail.

Table 4.5 Statistical distributions of geographic variables

Name		***Category***		***Observation***
phdloc	China	US	ROW	
share(%)	59.9	15.5	25.0	451
loc	China	US	ROW	
share(%)	65.7	14.9	19.5	451
duration	< 2 years	2 - 7 years	> 7 years	
share(%)	35.9	31.0	33.1	432

Note: The 2006 data are used for the variable *loc*.

4.3 Demographic variables

This section introduces the measurements of the rest of the demographic variables and their descriptive statistics. It also discusses their impacts on research productivity, since these variables mainly serve as the control variables in the regression analyses in the following two chapters. Some of them are common in social science literature, such as gender and age; while others are more specific to this study, particularly the three variables based on university rankings.

Gender (gender). Many studies have concluded that female scientists publish less than their male colleagues (Blackburn et al. 1991; Ayalon 2003), though it is debatable what factors lead to this gender gap of productivity. The conservative views tend to explain the gap based on “different” abilities and interests between the two sexes. Another line of research, a more liberal explanation, suggests that the male predominance of scientific contribution reflects various social effects favorable to male scholars. For example, Weaver et al. (1991) stresses three external factors hindering women’s academic achievements: gender differences in socialization and development, overt and covert discrimination, and social structural barriers. These factors together drive female scientists in the “outer circle of science” because they amplify the gender gap over time (Zuckerman, Cole, and Bruer 1991). Whatever the reasons are, we expect that the impact of being female on research productivity is negative.

Age. Studies on the relationship between age and productivity find mixed results. Hammel (1980) reports a slightly upward age-productivity curve and argues that scientific productivity increases or flattens with age, but does not necessarily decline. Cole (1979) observes that age has a curvilinear relationship with a single peak in six fields with cross-section data. One well designed study (Levin and Stephan 1991) also shows an inverse relationship between age and productivity after careful control for individual and cohort effects. Because age effects are mixed with quite a few intervening and mediator variables, its overall effect is probably not fixed.

Life cycle models, which are often adopted by these studies, assume that scientists allocate time and energy to maximize their utility function over academic career (Levin and Stephan 1991). This theory is inadequate because scientists may accumulate more working experience and academic resources over time, which raise their productivity substantially. We thereby hypothesize that the overall age effect is positive on productivity.

Age in this study is defined as an author's age in the year of writing, or one year ahead of the publication year due to the time lag. For example, one's age in 2005 corresponds to his publications in 2006.

Cohort. Demographers often emphasize the differences between "age effect" and "cohort effects". As the time range of the bibliometric data is only eight years (1998-2006), the cohort effects are hard to detect. Instead, the variable "*cohort*" can be used as a proxy of one's "academic age" in analysis of the cross-sectional data, because it is highly correlated with age. In the next two chapters, the two variables appear in different model specifications separately.

The operational definition of *cohort* is the graduation year of the bachelor degree. We further categorized it into four dummy variables for the purpose of analysis (see Table 5.4). It should be noted that *cohort* does not necessarily indicate ones' working experience. Some scientists might work for a high-tech company before attending their doctoral programs, while others already start to conduct research even in their master programs. The effect of cohort is expected to be similar to that of age – the older cohorts tend to have higher productivity than younger ones.

Quality of undergraduate education (quaunder). Undergraduate education has a long and positive impact on individual research productivity, but this impact is largely mediated by postgraduate education. Graduates of prestigious colleges are more likely to attend leading universities at doctoral level, which directly affects their later research ability. This variable is the major indicator for answering the first research question, since we attempt to analyze the selectivity of emigrant scientists in terms of their education background.

According to a recent evaluation report of Chinese universities (Wu 2009), we classified the Chinese colleges mentioned by the respondents into four tiers. A list in the report covers all the 34 top colleges in mainland China (or "A-class" colleges, to put it in the author's word) and ranks them by selected indicators in natural sciences[31]. The classification adopted here is primarily consistent with the ranking list, and it made some adjustments according to qualification of students in the colleges. For example, Zhejiang University is ranked second on the list, but the average qualification of its students is lower than that of students at Beijing University in terms of scores at the National Entrance Examination[32]. Zhejiang University is thereby moved down into the second tier, while Beijing University moves up to the first tier (see Table 5.7). Universities not appearing on the list belong to the fourth tier. Appendix III shows the detailed coding table of this variable.

[31] The Chinese version of the list is available online: http://edu.sina.com.cn/gaokao/2008-12-24/1805180859.shtml

[32] A Chinese online source offers the average score of major colleges in the past six years. It is available at: http://kaoshi.edu.sina.com.cn/collegedb/collegebang.php?_action=college_score_more&provid=1&wl=2&batch=11&syear=2008

Quality of graduate education (quagra). Doctoral education determines the initial research ability of a scientist, which has a persisting and significant effect on his later academic performance. Graduate school offers potential scientific talent a critical socializing environment, because it not only teaches knowledge and skills, but also cultivates norms and values (Hunter and Kuh 1987). An early study shows that graduates of major universities are more likely to be highly productive than graduates of the minor university (Crane 1965). In a following study focusing on 467 doctoral biochemists, Bayer and Folger (1966) find a low but positive correlation between the prestige of the doctoral institutions and citations to their works. Reskin (1977) also reports that the quality of the doctoral program has a significant effect on the chemists' productivity in their first professional decade. A study on young economists further supports these findings (Buchmueller, Dominitz and Hansen 1999). This variable is vital for testing the second hypothesis on the negative selectivity of return migration.

Three global university ranking lists are available for use by far - the Academic Rankings of World Universities generated by an institute at Shanghai Jiaotong University, the QS World University Rankings released by a multinational company, and the Performance Ranking of Scientific Papers for World Universities produced by an official agency in Taiwan. Each of them selects and sorts the top 500 universities at global level according to a set of specific criteria. Since faculty members at a university largely determine the quality of its doctoral programs, this study adopts the 2009 Jiaotong ranking list as a reference for coding the variable "*quagra*", since it emphasizes prestige and publication records of university scientists[33].

Each scientist in the sample reported the university where he received his highest degree. Some do not have a doctoral degree, and university of their master program is used as a substitute. A coding scheme aggregates all the universities into eight categories in accordance with their rankings on the Jiaotong list. Those out of the list are integrated into the eighth category. Table 4.6 presents the Jiaotong rankings and the percentage distribution of scientists graduating from these universities. The eight categories are further broken down to four or three classes for some analytical purposes.

Table 4.6 Distribution of scientists by ranking of graduate university

Category	*Jiaotong ranking*	*Percentage of scientists (%)*	*Cumulative percentage (%)*
1	1-50	11.7	11.7
2	51-100	5.8	17.6
3	101-150	3.8	21.4
4	151-200	2.2	23.5
5	201-300	31.7	55.3
6	301-400	10.3	65.6
7	401-500	26.5	92.1
8	Not on the list	7.9	100.0
Observation			451

Source: the author's calculation based on IHE (2009)

Research environment (resenvi). A sound research environment is a critical predictor of future production as it activates researchers' interests and stimulates performance (Hansen et al. 1978). The relationship between affiliation with a prestigious university and productivity is probably indirect, which is mediated by academic resources

[33] The features of the Taiwan list are very similar to the Jiaotong list, but we only obtained the data of the latter in EXCEL format after request to Prof. Qi Wang at Shanghai Jiaotong University.

such as caliber of senior mentors, collaboration with prominent scholars, higher visibility, and more funding opportunities (Cole 1970). Cole and Cole (1973) examined a sample of 120 physicists in the US and find that researchers at prestigious departments are more productive and more often cited than their colleagues at lower-ranked universities, which confirms the findings of a previous study (Crane 1965).

Some studies on scientists' job mobility further reveal the dominant effect of research environment. Long (1978) studies the job change of 179 male biochemists and find that productivity increases for those who have moved to more prestigious departments, but the effect of prior productivity on the prestige of the department seems weak. Long and McGinnis (1981) supports the idea that individual productivity tends to conform to the characteristics of a specific environment, but the chance of employment is not strongly influenced by research productivity. Allison and Long (1990) observed 179 academic job changes of researchers of natural scientists and find that a move to a more prestigious department leads to increasing productivity in terms of publication and citation rates, while a move to a less prestigious one has the opposite effect. The higher the ranking of a university, the more supportive its environment is expected to be, thereby producing a greater positive impact on individual productivity.

The variable *resenvi* is an important control variable for comparing the research performance between different migration groups. To be consistent with the measurement of *quagra*, it uses the same coding scheme based on the 2009 Jiaotong list. One's working affiliation is classified into one of the eight categories according to its ranking (Table 4.7). This variable is more often collapsed into three or two dummy variables for regression analysis. A few of scientists in the sample worked for public research organizations, such as NASA, NIH, and CAS (Chinese Academy of Sciences), which are not covered by any of the three university ranking lists. Codification of these institutions is based on the ESI database (Essential Science Indicator)[34], which collects the annual publication and citation data of the various types of research organizations in the world. We assigned each public institution the same code as a university, if the former's research performance in terms of total publication and average citation rate is similar to the latter's in a particular field. CAS is treated separately - all the institutes affiliated with CAS are combined with Beijing University and Tsinghua University in the first category because of the high status of CAS in the Chinese scientist community.

Table 4.7 Distribution of scientists by ranking of affiliation in 2006

Class	*Jiaotong ranking*	*Percentage of scientists*	*Cumulative percentage*
1	1-50	11.7	11.7
2	51-100	5.7	17.3
3	101-150	3.0	20.4
4	151-200	1.5	21.8
5	201-300	33.4	55.2
6	301-400	11.1	66.3
7	401-500	31.1	97.4
8	Not on the list	2.6	100.0
Observation			451

Discipline (field). It is common sense among bibliometricians that publishing activity and citation patterns differ greatly from one discipline to another. An early

[34] ESI is also part of the ISI "web of knowledge". It is accessible under the web page "Additional Resources".

empirical study investigated 23 disciplines at the national level and reports substantial variations of publication productivity between disciplines due to the characteristics of these disciplines (Baird 1991). Dietz and Bozeman (2005) find physicists and chemists receive more citations than biologists. These findings suggest control or normalization of field effects on citation-based indexes, in order to compare academic performance in different fields.

There are two variables related to the disciplinary factor in this study. The first one is the field to which a respondent's current department/school belongs in 2010. For example, one's field is mathematics if he works for the department of mathematics and statistics at a university. The survey also asked respondents to choose one major subfield in which they work from 24 options (see Q3 and Q4 in Appendix II). Their major subfields are further collapsed into four broad fields (mathematics, physics, chemistry, and biology), thereby constituting the second variable. The information of their minor subfields is mainly used for collecting the bibliometric data.

Professional status (prosta). Professional status across the academic ladder, from research assistant to full professor, is relatively identifiable and standard across universities in the world. Higher status implies a considerable increase in salary and reputation within the academic community. Promotion to a higher level of professional status has two opposite effects on individual research productivity. On the one hand, promotion may reduce one's incentives to publish more since one has acquired the higher position from the perspective of classic human capital theories. On the other hand, higher status helps one better mobilize external resources, including funding and collaboration opportunities, thereby increasing research output substantially. Considering the overall impact, we expect higher professional status raises individual research productivity.

The survey asked the respondents to report their professional status in the three observations years (see Q16 in Appendix II). It did not solicit information on tenure track because most scientists in China are tenured from the very beginning of their career. Nor did the survey distinguish full-time researchers from professors with teaching load, since the former only represent a small portion of the scientists in the sample. We codified the data and generated an ordinal variable with six values, with a further breakdown into four categories for regression analysis.

Administrative position (admin). Empirical observations show that senior scientists tend to devote more time to administrative tasks, as they become older and their productivity declines (Knorr 1979). However, contrary to people's general belief, higher administration positions might facilitate rather than inhibit scientific performance, because they bring more academic resources and research assistants (Pelz and Andrews 1976), which is probably the case in China.

One item in the questionnaire offers four options of administrative position, which range from a committee chair to a dean. A respondent can choose one option if he took an administrative job in a given year (see Q18 in Appendix II). This variable is further recoded as binary, with taking an administrative position as "1" and no such position as "0".

Visa category of returnees (visaret). This variable only applies to domestic scientists who had an overseas academic experience for at least six months by 2006. The survey asked returnee respondents to report their visa status during their last long-term[35] visit to a foreign country (see Q36-2 in Appendix II).

Table 4.8 shows the descriptive statistics of most of the demographic variables, as well as their expected impacts on research productivity.

Table 4.8 Statistical distribution of demographic variables and their impacts on productivity

Name	*Category*				*Reference group*	*Impact*	*Observation*
gender	male	female			male	-	438
share(%)	83.7	16.3					
age	26-40	41-50	51-64		NA	+	441
share(%)	47.5	44.1	8.4				
cohort	1977-83	1984-89	1990-96	1997-2003	1997-2003	+	438
share(%)	17.3	24.3	32.6	25.8			
quaunder	class1	class2	class3	class4	class4	+	440
share(%)	11.3	23.3	31.9	33.5			
field	mathematics	physics	chemistry	biology	physics	-	451
share(%)	24.9	24.0	32.7	18.4			
prosta	junior level	middle level	senior level		junior level	+	451
share(%)	41.3	29.2	29.5				
admin	no	yes			no	+	445
share(%)	82.3	17.8					

Note: 1. The sign "-" in the column "Impact" refers to a negative effect, and "+" refers to a positive effect.
2. "Junior level" of the variable *prosta* refers to doctoral students, post-docs, and assistant professor/researcher; "middle level" refers to associate profession/researcher; and "senior level" refers to full professor/researcher.
3. "Yes" of the variable *admin* refers to those with administrative positions.

[35] Here "long-term" refers an overseas trip no less than half a year.

Chapter 5 Migration Flows and Their Selectivity

What is the geographical distribution of the leading Chinese scientists in the world? In which regions are they spatially concentrated, and what are the roles of these regions in educating and employing them? In the presence of selective migration, who are more likely to leave, and who are more inclined to return?

This chapter mainly attempts to answer the above questions. Section 5.1 depicts global distribution of Chinese scientists in the three observation years. Section 5.2 identifies the positive selective trends of emigration and analyzes the propensities of foreign education and employment using logistic regression method. Section 5.3 shows the patterns of return migration by selected demographic indicators, and discusses its negative selectivity in terms of educational background.

5.1 Geographic distribution and migration flows

All the scientists in our sample received their undergraduate education in China, and some of them pursued overseas study after their college years. A total of 181 foreign-educated individuals obtained foreign doctoral degrees among the 451 scientists in the sample. The portion of foreign degree holders decreases from 40.1% to 33.9%, after we weighted the sample with the frequency weight[36]. All the descriptive analyses in this

[36] The generation of the frequency weight is described in Section 3.4.

dissertation are based on the weighted sample in order to improve the representativeness.

As Section 4.3 introduces, the locations of Chinese scientists are categorized into three regions: mainland China, the United States, and the Rest of the World (ROW)[37]. Their geographic distribution of Chinese scientists in the three regions had changed considerably between 1998 and 2006. Table 5.1 presents their regional proportions, the number of observations, and the extrapolated number of population. Overall, Chinese scientists at the leading global universities grew from less than thirty-five hundred to more than sixty-one hundred. The number of researchers at the eighteen leading Chinese leading universities increased steadily from less than twenty-five hundred to over four thousand[38], which implies an expansion by 63% in eight years. The talent pool of overseas Chinese expanded even more rapidly in the US (129%) and the ROW (98%). This finding is consistent with Hamilton (2009), which reports that almost all growth in foreign doctoral attainment in major fields of science and engineering in the US between 1994 and 2005 came from Chinese students.

Table 5.1 Geographic distribution of Chinese scientists, 1998 - 2006

Year	*China (%)*	*ROW (%)*	*US (%)*	*Total (%)*	*Observation*	*Population*
1998	71.6	13.3	15.1	100	253	3444
2002	64.9	14.2	21	100	351	4754
2006	65.7	14.9	19.5	100	451	6136

Note: The figures of population are extrapolated according to the frequency weight. The average of the frequency weight is 13.6, which means that eight more observations can raise an extrapolated figure by one hundred.

[37] The ROW mainly covers six English speaking countries (UK, Canada, Australia, New Zealand, Singapore, and Hong Kong), as well as other countries like Japan or Germany.
[38] It should be noted that not all researchers were formally employed in the figures. Doctoral students in their penultimate year before graduation are also included in the sample.

The share of domestic scientists decreased from 71.6% in 1998 to 65.7% in 2006, though their size had grown substantially. The US share increased by around 5% during the period, while the share of the ROW changed little. It seems the US, as the global talent magnet, became even more attractive to top Chinese scientists than before. In addition, the figures in 2002 are very close to those in 2006, implying a steady trend or balanced flows in the mid 2000's.

We further analyzed the geographic distribution by cohort, since some Chinese scientists moved abroad as early as three decades ago, and their intellectual impacts are quite different from younger generations. For the purpose of this study, scientists who received their bachelor degrees between 1977 and 1983 are defined as the early-reform cohort, and those who did so between 1984 and 1989 are defined as the pre-incident cohort. Here the "incident" refers to the Tiananmen Square protests in 1989. So those between 1990 and 1996 are defined as the post-incident cohort, and those between 1997 and 2003 as the millennium cohort (Table 5.2). The later cohorts generally consist of more scientists than the previous cohorts, which is the result of the expansive trend toward college enrollment and research personnel in China. The post-incident cohort has more observations than the millennium cohort, because some the latter's youngest members were still studying in their doctoral programs in 2006, thereby excluding them from the sample.

There are significant differences of emigration between the cohorts. The fourth column of Table 5.2 shows the proportion of Chinese scientists who obtained their highest degrees abroad by cohort. The pre-incident cohort has the highest proportion

(41.8%), while the post-incident cohort has the lowest one (26.9%). The other two cohorts are in between. The last column presents the share of emigrants in each cohort in 2006, and the indicators varies from 27.5% for the early-reform cohort to 38.4% for the millennium cohort. Although the two older cohorts have higher proportions of overseas students, their emigration rates in 2006 were lower, implying that some previous emigrants returned home. The opposite is true for the two younger cohorts and indicates that some of them went abroad after their doctoral graduation. The following analysis further confirms this contrast.

Table 5.2 Share of cohorts and proportion of overseas students and emigrants by cohort (%)

Cohort	*Year of bachelor degree*	*Share*	*Proportion receiving highest degree abroad*	*Share of total emigrants in 2006*
Early-reform	1977-1983	17.3	35.7	27.5
Pre-incident	1984-1989	24.3	41.8	35.2
Post-incident	1990-1996	32.6	26.9	32.4
Millennium	1997-2003	25.8	32.8	38.4
Total		100	33.5	33.8

Population change in a country is determined by four demographic factors – birth rate, death rate, emigration rate, and immigration rate. The impact of death rate is negligible in this study, since only a small fraction of Chinese scientists die before sixty[39], and they do not even retire by that age. The change of the domestic talent pool depends on domestic "production" of skilled workers, emigration and return migration,

[39] The death rate of the target population is unknown from other sources, though a survey reports that the average life expectancy of intellectuals is less than that of general population in China (Jonkers 2010, Section 2.4.3).

while the size of the scientific diaspora is affected only by emigration and return migration. Next we analyze the characteristics of the migration flows based on the stock statistics in the three observation years.

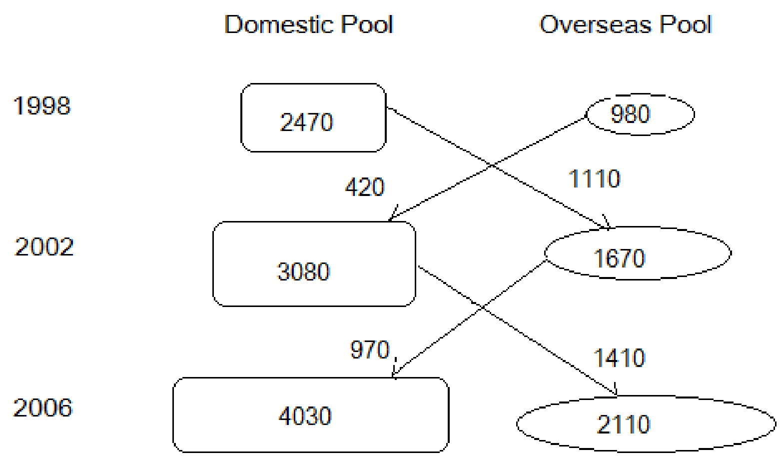

Figure 5.1 Stock and flow estimates of domestic and overseas talent pools

The stock of emigrant scientists from China was more than doubled between 1998 and 2006 according to the extrapolated population based on our data[40] (Figure 5.1). The number of returnees tripled from six hundred to nearly two thousand in the same period. Here returnees are broadly defined as those who have overseas experience for at least two years. Over four hundred returnees moved back to China between 1998 and 2002, and nearly one thousand did so between 2002 and 2006, if we assume that they did not move abroad again after a temporary return. After deduction of the returnees, we also estimated

[40] The extrapolation of population is not very accurate, so we only present the rough estimations in the text. More concrete figures are shown in Figure 5.1.

that the emigration flows brought eleven hundred and fourteen hundred scientists to the host countries respectively during the two periods.

The number of stayers remained around two thousand, and their share decreased substantially from over half (54.2%) in 1998 to one third (33.3%) in 2006 (Table 5.3). The decreasing share of stayers does not imply that few domestic doctoral graduates joined the group. Instead, many previous stayers went abroad as post-docs or visiting scholars during the period, and they became returnees after moving back. The growth of such returnees was larger than that of new stayers, therefore we did not observe a substantial increase of stayers.

Table 5.3 Distribution of migration groups, 1998-2006 (%)

Year	*Stayer*	*Returnee*	*Emigrant*	*Total*	*Emigration rate*	*Return rate*
1998	54.2	17.4	28.4	100	28.4	38
2002	43.4	21.5	35.2	100	35.2	38
2006	33.3	32.4	34.3	100	34.3	48.6

Note:
1. Returnees are defined as those who have overseas experience for at least two years.
2. Emigration rate is defined as the ratio between emigrants and all Chinese scientists in an observation year.
3. Return rate is defined as the ratio between returnees and all Chinese scientists with overseas experiences, including both emigrants and returnees.
4. The population figures are slightly different from those in Table 5.1 because of the weighting and rounding method adopted here.

Returnees represented almost one third of all Chinese scientists in 2006, while their share was just 17.4% in 1998. Although the overall return rate remained unchanged between 1998 and 2002, it jumps to 48.6% in 2006, which indicates that half of those scientists with international experience for at least two years had returned to China by 2006. Meanwhile, the overall emigration rate only increased by six or seven per cent. It seems a balanced brain circulation, instead of a lop-sided brain drain, had started to occur in this period. However, it is necessary to analyze the composition of returnees to confirm this trend.

The return flows might be considerably different by cohort in terms of age and position, so we further estimated their shares in 2006 (Table 5.4). Returnees represented a larger share in the two older cohorts, which is consistent with our findings based on Table 5.2. Since the older cohorts usually have more chances to visit abroad than younger ones, they are more likely to become returnees and their return rate is also higher. Three out of five scientists (61.2%) of the early-reform cohort had returned to China by 2006, while less than 40% (39.8%) of the millennium cohort did so. The younger cohorts tend to have higher emigration rates, those having moved abroad might not yet be prepared to return yet.

Table 5.4 Distribution of migration groups by cohort, 2006 (%)

Cohort	*Stayer*	*Returnee*	*Emigrant*	*Total*	*Emigration rate*	*Return rate*
Early-reform	29.2	43.3	27.5	100	27.5	61.2
Pre-incident	27.8	37.1	35.2	100	35.2	51.3
Post-incident	37.7	29.9	32.4	100	32.4	47.9
Millennium	36.2	25.4	38.4	100	38.4	39.8
Total	33.4	32.8	33.8	100	33.8	49.2

Note:
1. The definitions of returnees, emigration rate and return rate are the same as those in Table 5.3.
2. The figure of total population is slightly lower than that in Table 5.3, because of there are several missing values of the variable “*cohort*”.

The nature of brain drain depends on emigrants’ study and work locations. Since the broad definition of returnees include both foreign degree holders and visiting scholars, it is necessary to distinguish the former from the latter. It is also important to differentiate emigrants trained in China from those trained in foreign countries. Hence we categorized all Chinese scientists into five types by the definitions in Table 5.5. They are defined according to the different combinations of their locations of highest degree and working affiliation. For example, an emigrant scholar is a scientist who obtained his highest degree in China and worked at a foreign institution in a given year. Stayer scientists and returnee scholars are further differentiated by their overseas duration.

Table 5.5 Definitions of five migration types

Type	*Location of highest degree*	*Location of affiliation*	*Overseas duration*
Stayer	China	China	less than two years
Returnee scholar	China	China	more than two years
Returnee student	Foreign countries	China	NA
Emigrant scholar	China	Foreign countries	NA
Emigrant student	Foreign countries	Foreign countries	NA

Emigration of a Chinese scientist can take two forms - directly moving abroad as an independent researcher or indirectly immigrating abroad after acquiring a foreign doctoral degree. We designate the former as "emigration of scholars" and the latter as "emigration of students". The definitions of "emigrant scholar" and "emigrant students" are derived accordingly. Thus, "returnee students" refer to foreign degree holders who returned to China, and "returnee scholars" refer to domestically trained researchers who returned after staying overseas for two years or more.

The dichotomy is very helpful in revealing the composition of the scientific migrations between China and the host countries. The absolute majority of returnees were composed of returnee scholars between 1998 and 2006 (Table 5.6), and returnee students represented around 20% of all returnees. By contrast, most emigrant scientists obtained foreign doctorates before they were formally employed abroad. Emigrant students took the lion's share of China's research diaspora, and their proportion kept close to 80% in the period. In this sense, China's scientific emigration is different from the exodus of Jewish scientists to America in the 1930's (Waldinger 2010) or the outflow of Russian scientists to the West after the Cold War (Ganguli 2010). It does not even resemble the emigration of European researchers to the US in recent years (Docquie and Rapoport 2011, 39-40), in which cases most migrants have already become full-fledged scientists before their relocation.

Table 5.6 Distribution of five migration types, 1998-2006 (%)

Year	*Stayer*	*Returnee student*	*Returnee scholar*	*Emigrant student*	*Emigrant scholar*	*Total*	*Emigration rate of scholars*	*Return rate of students*
1998	54.2	3.4	14.0	22.6	5.8	100	7.9	13.2
2002	43.4	3.7	17.8	26.0	9.1	100	13.0	12.3
2006	33.3	7.4	25.0	26.5	7.8	100	11.9	21.9

Note:
1. Emigration rate of scholars refers to the ratio between emigrant scholars and domestic degree holders.
2. Return rate of students refers to the ratio between returnee students and foreign degree holders.

The overall return rates in Table 5.3 seem too high to be consistent with the increasing stay rates over time for Chinese doctoral graduates of science majors in the US (Kim, Bankart, and Isdell 2011). This apparent mismatch can be explained, however, by the high return rates mainly resulting from increasing return scholars. If we exclude returnee scholars from the statistics, the return rate of returnee students is as low as

13.2% in 1998 (see the last column, Table 5.6). It jumped to 21.9% in 2006, but remained at a low level.

However, we might exaggerate the gravity of the scientific brain drain, since China did not train the emigrant students at the doctoral level. Most emigrant scientists had not accumulated enough expertise to conduct research independently when they pursed overseas study as college graduates. With the exception of those sponsored by the Chinese government, they financed their tuition fees and living expenditure from private sources, particularly scholarships provided by foreign universities. Foreign education received by returnee students probably outweighs their prior education before departure. However, simply indicators of migration alone do not reflect their added human capital in foreign countries.

It is more reasonable to view emigration of scholars as a brain drain in its real sense, but the corresponding emigration rate is merely 10% or so. In addition, foreign stays of most emigrant scholars are temporary by nature, as three quarters of them (76.1%) had returned by 2006. The emigration of Chinese scholars is better regarded as unfinished brain circulation, rather than a permanent exodus. According our estimation, only fifty foreign degree holders moved back to China between 1998 and 2002, but they were followed by a large flow of nearly three hundred between 2002 and 2006, who were possibly lured back by improving research conditions in China. The number of returnee students (460) almost caught up with that of emigrant scholars (480) in 2006, which probably counterbalanced the latter's drain effect.

Overall, all the migration flows had been doubled or tripled during the observation period. The number of return students increased dramatically by three times, partly because the original base was small. Their return did not shrink the size of China's scientific diaspora, because even more emigrant students went abroad. The outmigration of Chinese scientists in turn barely outstripped the growth of research personnel in China, which was driven by an increasing enrollment at leading universities.

5.2 Positive selectivity of emigration

As Section 3.1 argues, the question of "who migrates" might be more important than "how many migrate". This section analyzes the selectivity of emigration flows in terms of several demographic indicators. In general, emigrant scientists did not constitute a random sample of domestic scientists but tended to be self-selected according to specific characteristics.

To begin with, we tackle the gender dimension briefly, though it is not the focus of this dissertation. The outmigration of Chinese scientists was considerably gendered. Female scientists represented only 12% of foreign degree holders, while they represented 18.5% of domestic degree holders. 7.7% of emigrant scientists were female in the US in 2006, and 10.9% of all overseas scientists were female, while one out of five scientists (19.1%) was female in mainland China. The two gender gaps are statistically significantly after we tested their proportional differences (p-value < 0.05). The lower proportion of female scientists in the Chinese research diaspora might reflect a strong sorting mechanism, as well as social discriminations, since women scientists generally exhibit lower productivity than men (see Section 6.2) and they are less encouraged to pursue overseas study in China.

By contrast, the age profile of Chinese scientists differs little by migration group. Their average age and median age in 2006 is 37 years with a standard deviation of 6.6 years. The average age of returnees (38.7) is two years older than that of stayers and emigrants (36.4 and 36.7, respectively), which is partly caused by the higher concentration of returnees in the older cohorts (Table 5.4).

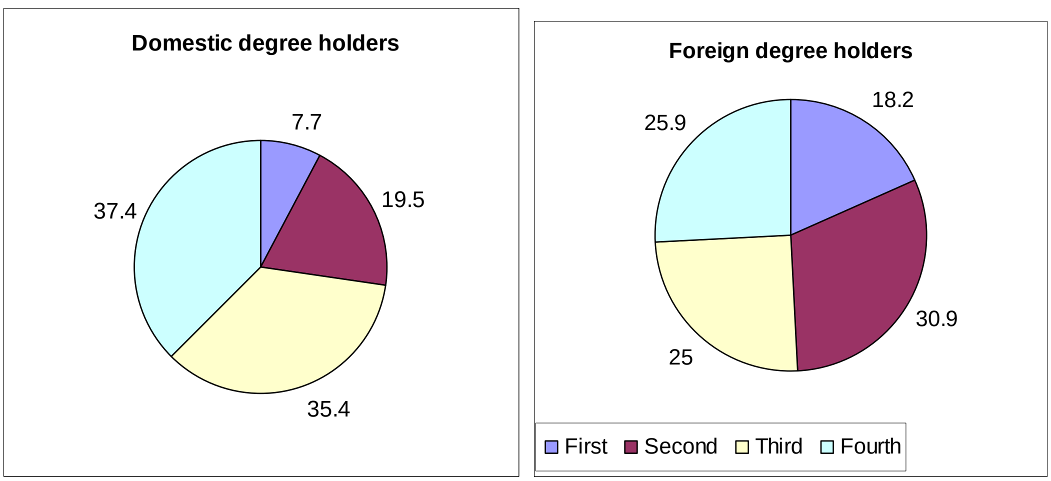

Figure 5.2 Composition of domestic/foreign degree holders by tier of college

As a gross indicator of the quality of graduates, college rankings substantially distinguish emigrant scientists from those left behind. The selective process of emigration has two main stages. The first stage determines access to foreign doctoral education. We use "domestic degree holders" to designate those who were awarded their highest degree in China[41], and adopt "foreign degree holders" to refer to those who received their

[41] Here "the highest degree" is more accurate than "doctoral degree", because some domestic scientists only obtained master degrees.

doctoral education abroad. We find that the latter were much more likely to graduate from prestigious colleges in China than the former. Nearly half (49.1%) of foreign degree holders obtained their bachelor degrees from colleges in the first or second tier, while only over a quarter (27.2%) of their domestic peers did so (Figure 5.2). The proportion of foreign degree holders was also much higher among college graduates in the first tier (54.4%) and second tier (44.4%) than in the two low tiers (Table 5.7).

Table 5.7 Share of foreign degree holders by tier of college

Tier	*Example*	*Share of foreign degree holders (%)*
First	Peking, Tsinghua	54.4
Second	Zhejiang, Fudan	44.4
Third	Nankai, Shandong	26.3
Fourth	Tianjin, Hunan	25.9
Total		33.6

Note: the column “Example” only gives the short form of college names.

Access to doctoral education in the US was even more selective. According an NSF report, the largest number of Chinese doctoral graduates in the US came from three best Chinese universities - Peking University, Tsinghua University, and the Science and Technology University in China (NSF 2008). The findings based on our sample are consistent with the NSF report. Although undergraduates from Peking University and Tsinghua University represent one tenth (11.3%) of all the Chinese scientists in the weighted sample, both of the universities contribute a quarter (25.8%) of Chinese doctoral students in the US. Among their alumni scientists with foreign degrees, four out of five obtained their doctorates in the US, while the remaining one obtained a degree in the ROW countries.

Furthermore, the selectivity of foreign doctoral programs turned stronger over time. Despite of the increasing stock of foreign degree holders, the number of scientists trained abroad in each cohort did not grow substantially. According to our estimates, nearly four hundred of the early-reform cohort received a foreign education, and over six hundred of the pre-incident cohort obtained foreign degrees, but a little more than five hundred of each of the two younger cohorts did so. This stable trend implies that the competition for foreign education might have become more intense in recent years, as applicants of foreign doctoral programs probably increased substantially.

The early-reform cohort was perhaps very different from the later cohorts in terms of selectivity, because the measurement used here might be less accurate in evaluating the quality of undergraduate education in the initial years after the restoration of the national entrance examination. In addition, worker-peasant-solider students, legacies of the Culture Revolution, were still studying at Chinese universities in that period. The share of graduates from prestigious universities among foreign degree holders has demonstrated a clear increasing trend since the mid 1980's (Figure 5.3). Over one third (35%) of foreign degree holders in the pre-incident cohort graduated from colleges in the first or second tier, while 40% in the post-incident cohort did so. The positive selectivity became most intense for the millennium cohort, as three fourth of its foreign educated members are alumni of the upper two tiers of colleges. In addition, the stronger selectivity might partially result from the enrollment growth at prestigious colleges in China, as they admitted many students who would have otherwise attended less prestigious institutions.

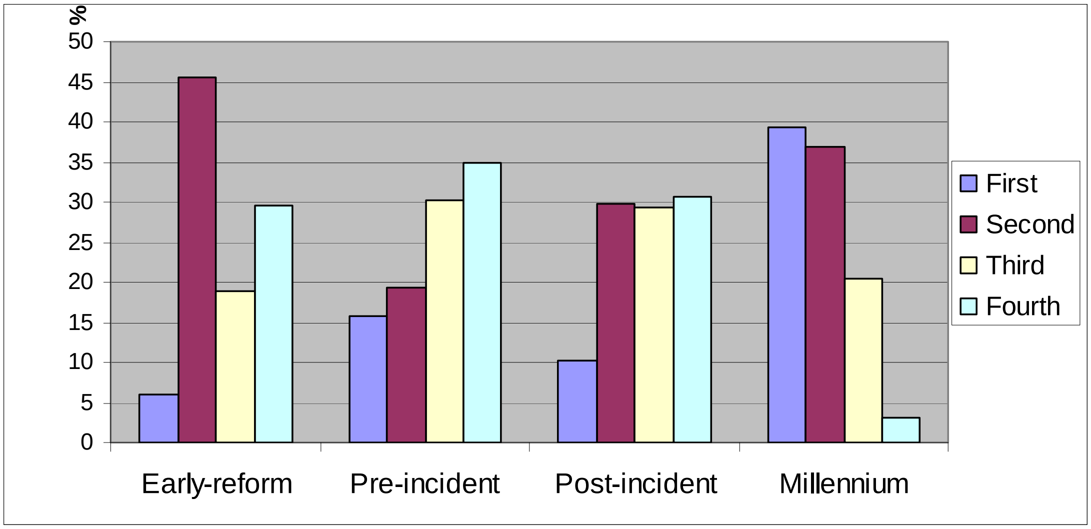

Figure 5.3 College background of foreign degree holders by cohort

The second stage of the emigration process selects faculty members for foreign universities from doctoral graduates. The transition to employment causes only a few geographic movements, because most graduates seek jobs in local academic markets. However, Chinese scientists can obtain permanent permission of residence after formal employment in their host countries, which largely shapes the final outcome of the brain drain. Figure 5.4 shows the geographic distribution of Chinese scientists' work affiliations in 2006, ordered by the rank of the universities where they obtained their degrees. Here we only focus on formally employed faculty members, and exclude doctoral students and post-docs. For the purpose of simplicity, the top fifty institutions are grouped as "Class I", universities with rankings between 51 and 200 as "Class II", those between 201 and 400 as "Class III", and those below 400 as "Class IV".

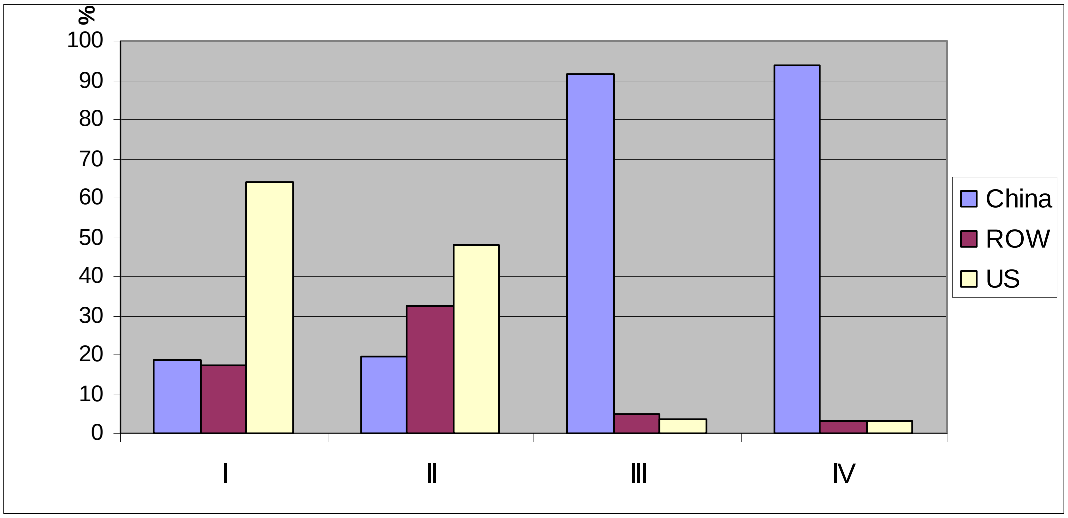

Figure 5.4 Location of Chinese scientists' affiliations in 2006 by class of graduate university

The preference for the US as the destination of choice for outstanding Chinese graduates is very clear from the statistics. Almost two thirds of the doctoral graduates in Class I were employed in the US in 2006, while nearly 20% worked in China (18.7%) and the ROW (17.3%), respectively. The geographic distribution of Class II is similar to that of Class I, though the ROW took a larger share of overseas scientists (32.3%). By contrast, research jobs in China were taken by the overwhelming majority of scientists in Class III (91.5%) and IV (94%), most of whom graduated from Chinese universities. Since no Chinese university was ranked in the top 200 institutions (Class I and II) on the Jiaotong 2009 list, we further compared the flow of domestic degree holders with that of foreign degree holders in Class III and IV. We find that only 4% of the former group were formally employed in foreign countries in 2006, and one third (33.6%) of the latter group had stayed abroad by then, though their stay rates were a much lower than foreign degree holders' in Class I and II.

Overseas scientists also differed significantly from their domestic peers by research field. As Chapter 4.2 introduces, the major subfields of Chinese scientists are collapsed into four broad disciplines - mathematics, physics, chemistry, and biology[42]. We find that the share of mathematicians was significantly smaller in the domestic talent pool (21.6%) than in the overseas pool (31.3%) by comparing the compositions of the two groups (Table 5.8). By contrast, there were more chemists proportionally in China (35.6%) than in the diaspora (27.1%). No substantial differences exist between the shares of physicists and biologists by region, as their gaps were less than 5% (see the column "Difference" in Table 5.8). The proportional differences were closely related to the emigration rates of scientists in each discipline, as 43% of Chinese mathematicians at leading global universities worked abroad in 2006, while only 28.4% of chemists did so. The high emigration rate of mathematicians might partially result from the fact that their knowledge is more internationally transferrable than knowledge in other disciplines. The low emigration rate of chemists was possibly caused by the size of the disciplinary group, as chemistry had the largest number of scientists in the four broad fields. Biologists constituted the smallest group and they were also very likely to move abroad. A closer investigation of the large subfields further supports these findings[43]. For example, scientists of computational mathematics had the highest emigration rate (44%), while those of physical chemistry have the lowest rate (23%).

[42] The broad disciplines are largely consistent with the departments of the respondents' affiliations, except that some researchers in departments of biology identified their major as subfields in chemistry, particularly biochemistry.

[43] "Large subfields" refer to the five subfields with more than 25 observations in the sample.

Table 5.8 Chinese scientists by field and location, 2006 (%)

Discipline	*Domestic*	*Overseas*	*Difference*	*Emigration rate*
Mathematics	21.6	31.3	9.7	43.1
Physics	25.6	21.0	-4.6	30.0
Chemistry	35.6	27.1	-8.5	28.4
Biology	17.2	20.6	3.4	38.5
Total	100.0	100.0	0.0	34.3

Note: Figures in the column "Difference" is calculated as the difference between the percentage in the column "Overseas" and that in the column "Domestic".

Since multiple factors influence a Chinese scientist's chance of emigration, we used logistic regressions to disentangle their specific effects on foreign education and employment[44]. Before presenting the models and results, it is necessary to discuss the use of weights for regression analysis. Although social scientists generally use sampling weights to generate unbiased estimates in descriptive analysis, it is more complicated to decide whether one should use weights in regressions, since the adoption of weights has both positive and negative consequences. Winship and Radbill (1994) find that unweighted estimates are unbiased and have smaller standard errors than weighted ones, when sampling weights are solely a function of independent variables. Since this condition applies to the weights used in this study, we decided to report unweighted estimates.

As most of the independent variables in the logistic regressions are dummy variables, here we present the regression results in the format of odds ratios for easy interpretation. The odds-ratio is the exponential transformation (antilog) of the associated coefficients. For a dummy variable representing a category X, the odds-ratio associated

[44] Although probit models are generally considered to generate more precise estimation, logit models perform just as well and have the advantage of computational simplicity (Kropko 2007).

with X stands for the ratio of the odds of this category to that of the reference group, other things being equal. The effect of a variable is positive (negative) when the odds-ratio is larger (smaller) than one. For instance, an odds ratio less than one for female (versus male) indicates that females are less likely to receive foreign education than males; otherwise females are more likely to do so than males.

The first logit model (Model 5-1) focuses on the determinants of foreign doctoral education. The dependent variable is dichotomous – whether a Chinese scientist obtained his highest degree from a foreign university or not. It has two specifications, whose explanatory variables are specified in Table 5.9, as well as their odds ratios and statistical significances. To control for the effects of personal characteristics, we included variables for gender (male=0, female=1), tier of college (the third tier as the reference group), and field (chemistry as the reference group). Since age and cohort are highly correlated ($r < -0.9$), they are separated in the two specifications to avoid the problem of multi-collinearity. This difference aside, the results of the two specifications appear very similar. The fit of the second specification is slightly better than the first in terms of their pseudo R-square.

The results of the first specification shows that the odds ratio between females and males differs by a factor of over 0.5, indicating women scientists are considerably less likely to receive foreign education than men of science. The odds of overseas study increase by nearly 3% with an additional year of age, which is consistent with the cohort effects in the second specification. Compared with the pre-incident cohort, the later two cohorts are less likely to obtain a foreign doctoral degree. At the first glance, this finding seems counterintuitive as the number of Chinese overseas students has grown rapidly from the beginning of 1990's. However, more applicants also mean more intense competition, and proportionally fewer students can be admitted by Western top universities. In addition, the odds for biologists are 1.2 to 1.5 times higher than that for chemists, with the relatively high odds of physicists and mathematicians in between.

Table 5.9 Explaining foreign education propensity of Chinese scientists

Explanatory Variable	***Odds Ratio （Model 5-1 ）***			
	Specification I		***Specification II***	
Female (vs. Male)	0.557881	*	0.506072	**
Age	1.028971	*		
Cohort (Reference group = Pre-incident)				
Early-reform			0.723037	
Post-incident			0.445025	***
Millennium			0.43936	***
Tier of college (Reference group = the third Class)				
First	3.101179	***	3.652348	***
Second	2.225365	***	2.682109	***
Fourth	0.963447		1.184703	
Field (Reference group= Chemistry)				
Mathematics	1.889122	**	1.837182	**
Physics	1.967458	**	1.680064	*
Biology	2.509917	***	2.228898	***
Observation		419		421
Pseudo R^2		0.0667		0.0827

Note: *p<0.1, **p<0.05, ***p<0.01

With regard to the effects of college education, graduation from the first tier tripled the odds of foreign doctoral education and graduation from the second tier doubled them when compared with graduation from the third tier. The fourth tier had no significant effect relative to the third. These results show clearly that the best of the best were prone to study abroad. In addition, we examined the selectivity of American education among all foreign degree holders using a similar model. Other things being equal, the odds of obtaining a doctorate in the US for graduates from the first-tier colleges were 14.6 times higher than they were for those from the fourth-tier. At a high level of significance, the odds ratios of studying in the US for graduates of the second and the third tier relative to the fourth tier were 4.5 and 2.7, respectively.

Next we attempted to test the effects of the selected predictors on the odds of foreign residence in 2006 upon completion of one's highest degree, so Model 5-2 only covers those who graduated by 2006. It has two specifications similar to Model 5-1, but tier of college is replaced with class of the university where the doctorates were obtained (Table 5.10)[45]. Although the odds ratio between females and males (0.697) is close to that in Table 5-9, there was no statistically significant difference by gender, indicating that the gender gap in the scientific emigration might be mediated by their access to foreign education. Contrary to the age effect on foreign education, we find an additional year reduced the odds of living abroad in 2006 by nearly 4.4%, but no clear cohort effect is detected. Although older Chinese scientists were more likely to obtain foreign degrees than younger ones, they were less likely to stay abroad. The odds of foreign stay differed enormously by class of university. Graduates from universities in Class I and II were far more likely to work in foreign countries than those from Class III, as the former's odds ratios were around twenty times higher than the latter's. By contrast, the odds of staying

[45] Duration is a stronger predictor of overseas stay, as one additional year outside China raises the odds of foreign stay by 17.6% if it is included in the model. However, we have to omit this variable because it is highly correlated with university rankings (correlation coefficient = -0.5741).

abroad for graduates from Class IV were only over a third (37.7%) of that for those from Class III. Additionally, we find no significant disciplinary disparities between the four broad fields, except that the odds of foreign employment for biologists were twice as high as that for chemists.

Table 5.10 Explaining foreign employment of Chinese Scientists in 2006

Explanatory Variable	*Odds Ratio (Model 5-2)*			
	Specification I		*Specification II*	
Female (vs. Male)	0.697081		0.726218	
Age	0.956155	**		
Cohort (Reference group = Pre-incident)				
Early-reform			0.540132	
Post-incident			0.88419	
Millennium			1.038477	
Class of university (Reference group = Class III)				
Class I	23.26381	***	26.68916	***
Class II	19.36162	***	17.08054	***
Class IV	0.376839	***	0.408373	**
Field (Reference group= Chemistry)				
Mathematics	1.196233		1.165353	
Physics	1.276693		1.184314	
Biology	2.098325	**	2.035634	**
Observation		402		400
Pseudo R^2		0.3339		0.3252

Note: *p<0.1, **p<0.05, ***p<0.01

The last part of this section presents some mixed evidences of the “brain gain” effects. The early researchers of brain drain argue that the effects of skilled emigration can induce a “ladder effect”, as remaining workers match to higher positions that they would have not taken without emigration (Bhagwati and Hamada 1974). Accordingly we may expect that emigration of the best college graduates leads to lower quality of domestic doctoral students at prestigious universities, as graduates from less prestigious colleges have more opportunities to attend prestigious ones for further study. However, the prospect of emigration would encourage more students at top colleges to pursue a scientific career, and those who fail to be admitted by foreign universities might attend domestic doctoral programs. According to the third hypothesis in Section 2.3, a field with a higher emigration rate is expected to have more qualified doctoral students in China in terms of their college rankings.

The statistical analysis shows that 34.1% of domestic mathematicians graduated from colleges in the first and second tier, while 28% of physicists and 25.7% of chemists did so, respectively. These differences seem supportive of our hypothesis, as mathematics has a higher emigration rate than the other two fields. However, biology, another field with a high emigration rate, attracted doctoral students of relatively lower quality, as around 20% (19.3%) of domestic biologists graduated from upper-level colleges. A close examination reveals that the qualification of doctoral students in biology had even declined over cohorts. The proportion of the upper-level college graduates among domestic doctoral students of biology dropped from 21.8% in the early two cohorts to 17.7% in the latter two, while the proportion for students of mathematics rose from 31% to 35.9% over cohorts. Here we did not find consistent evidences supporting the brain gain effect, and the differences might result from disciplinary developments rather than emigration rates.

The findings are also mixed at the level of the most prestigious universities. Leading universities in China, such as Peking University and Tsinghua University, are sometimes nicknamed "preparatory schools" for overseas Chinese students. The large number of their overseas alumni may facilitate the migration process of later comers and diminish the risks and costs of overseas study through networking activities. In addition, they are generally viewed as role models in the eyes of younger college students, thereby shaping the social memory of migration as a path to success. We may expect that graduates from prestigious colleges are more sensitive to emigration prospects. However, we find no association between disciplinary emigration rates and qualification of doctoral students at prestigious universities[46] in China, except that PhD students of mathematics were more likely to graduate from colleges in the first and second tier than those of the other three disciplines. It is still far from clear how overseas study opportunities influenced Chinese students' choices of major.

5.3 Negative selectivity of return migration

Dr. Yigong Shi, who was a naturalized American citizen and had stayed in the US for eighteen years, shocked his colleagues at Princeton University by returning to China in 2009. As a world-leading scientist of cell studies, Shi resigned from Princeton and took the position of the dean of school of life sciences at Tsinghua University (Lafraniere 2010). Chinese academics are not unfamiliar with such high-profile cases, and they might be impressed by China's ability in luring outstanding overseas talent to return home. As is shown below, however, the mainstream of return migration to China was negatively selected relative to its scientific diaspora.

[46] Here prestigious universities are defined as Chinese institutions ranked between 201 and 400 on the Jiaotong 2009 list.

The demographic profile of broadly defined returnee scientists differed slightly from that of emigrants by gender and age. Female scientists represented 10.9% of emigrants in 2006, and their portion in returnees was just one percent higher (12.4%), and the disparity is statistically insignificant ($p>0.1$). However, there are more women scientists among returnee scholars (13.3%) than returnee students (9.4%)[47]. The disparity indicates that females with foreign degrees were less likely to return than those with domestic degrees, since foreign degree holders and domestic scholars with overseas experience had similar proportions of females (12% and 11.2%, respectively). Kim et al. (2011) also find that female degree holders were consistently more likely to stay in the US in the past three decades, and they suggest that highly skilled women may have more degree relevant opportunities in the US compared to their home countries.

The average age of returnee students (40.9) was around four years older than that of emigrant students (36.8) in 2006; so was the average age of returnee scholars (38) relative to that of emigrant scholars (34.9), which can be explained by the previous finding that older cohorts were more likely to be returnees (see Table 5.4). The results are consistent with Kim et al. (2011), who find that doctoral students from China in the 1990s had a significantly lower return rate (8.3%) than their counterparts in the 1980s (25.9%), and the return rates remained stable from the 1990s to the 2000s.

The propensity to return differed substantially by university ranking among foreign degree holders. The higher the ranking of an emigrant's university of doctorate, the less likely it was that he returned to China for employment by 2006 (Figure 5.5). Returnees

[47] The definitions of returnee scholars/students can be found on Table 5.5.

represented over one tenth of foreign degree holders in Class I (11%) and II (13.5%), while they constituted one third of those in Class III (35.5%) and the absolute majority in Class IV (59.1%). Overall, China received one out of five (21.9%) overseas scientists trained abroad by 2006, but most of these returnees (61.2%) graduated from foreign universities ranked below 200 on the 2009 Jiaotong list. In addition, 82.9% of the returnees with foreign degrees were awarded doctorates in the ROW, and only the remaining 17.1% were trained in the US, the global superpower of science. We may conclude that "the worst of the best" were prone to return to China.

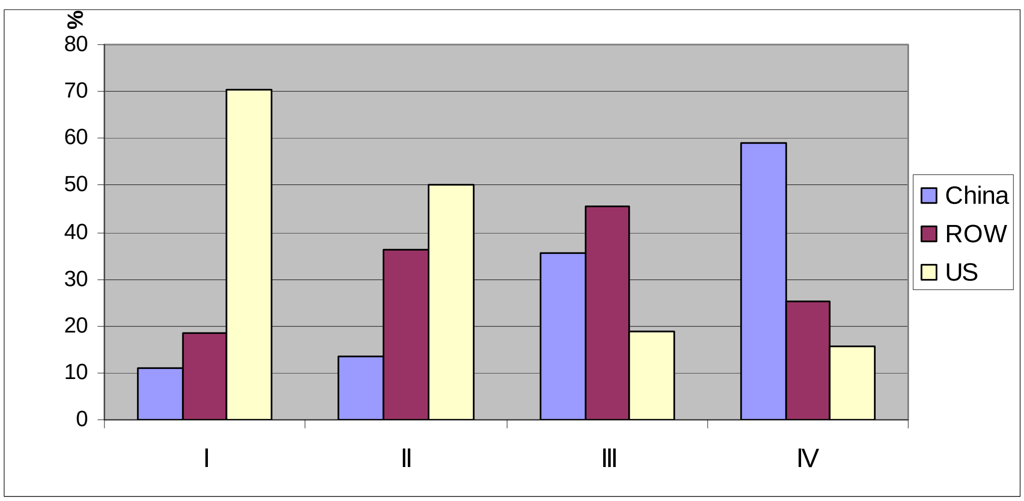

Figure 5.5 Locations of foreign degree holders in 2006 by class of graduate university

The migration of returnee scholars is a different story. As Section 5.1 reports, most domestic degree holders who had stayed abroad for at least two years had returned to China by 2006. There were around 15 thousand returnee scholars in China in 2006, and nearly five hundred emigrant scholars in foreign countries[48], who would probably return later. We categorized all domestic degree holders into Class III (ranked 200-400) and IV (ranked 400 and below), since no Chinese university was ranked above 200 on the 2009 Jiaotong list. Two thirds (66.7%) of return scholars graduated from Chinese universities in Class III, while nearly four fifth (78.6%) of emigrant scholars did so. The return flow of scholars appeared to be negatively selected, but its selectivity was much weaker than that of returnee students in terms of doctoral education background.

Contrary to our expectation, the negative selectivity of return migration became stronger between 1998 and 2006. The share of graduates from Class I and II among returnee students declines from 56.8% in 1998 to 38.8% in 2006[49] (Table 5.11). We may speculate that a few outstanding scientists are more likely to move back at the initial stage of the "reverse brain drain", if they can take important positions in their home country. As the national economy grows and research environment improves, more overseas scientists are lured back and the average qualification of returnees decreases with the return tide. Mediocre researchers might have stronger motivations to return than excellent ones, if the former do not foresee a bright future abroad, and try to take advantage of favorable conditions in the home country. With regard to returnee scholars, the share of graduates from Class III also fell by around 9% during the period, probably because many more domestic scientists visited foreign research institutions over time. As supplementary evidence, the share of Class-III graduates among emigrant scholars also

[48] The definitions of returnee/emigrant scholars can be found on Table 5.5.
[49] The statistics of 1998 should be interpreted with caution since there are less than ten observations of returnee students in the sample for that year.

decreased by a similar percentage correspondingly.

Table 5.11 Class of graduate universities of returnees by year (%)

Year	***Returnee student***			***Returnee scholar***		
	Class I & II	Class III & IV	Total	Class III	Class IV	Total
1998	56.8	43.2	100	76.9	23.1	100
2002	46.0	54.0	100	68.9	31.1	100
2006	38.8	61.2	100	67.4	32.6	100

Note: We exclude returnee scholars who obtained doctorates after the corresponding observation year.

Scientists in the four broad fields faced different pressures and opportunities affecting their return decisions. Foreign degree holders in mathematics were less represented among returnee students (21.7%) in 2006 relative to their share among emigrants (32.9%), while those of biology seemed over represented (27.4% vs. 19%). Qiao and Stephan (2007) find 67 biologists with US degrees at 34 Chinese "985 institutions"[50], and by simple calculation they estimate that these returnees represent approximate 7% of Chinese biologists trained in the US (Freeman, Stephan and Trumpbour 2008). We find the returnee students of biology represent 11% of all US-trained biologists in our sample. There were no significant differences in the fields of physics and chemistry.

Mathematicians represented a smaller portion of returnee scholars (14.6%) than emigrant scholars (25.8%); as do biologists (14.2% vs. 26.2%). Just as more mathematicians tended to emigrate proportionally, they were also less likely to return.

[50] Project 985 aims to promote the Chinese higher education system under the call of President Jiang Zemin at the 100th anniversary of Peking University on May 4, 1998. Project 985 sponsored 39 universities and assigned goals and funding to each university.

Biologists with foreign degrees were prone to return, while those with domestic degrees tended to stay abroad. Interestingly, returnee scholars of physics were far more likely to return (37.6% vs. 12.3%). A large number of domestic physicists might have already gain international experience, so not many of them sought to stay in foreign countries by 2006.

We adopted two logit models to further investigate the effects of different predictors on return migration (Table 5.12). The regression results are largely consistent with the above descriptive analyses. The dependent variable of the two models is binary – we coded one's location in China in 2006 as "1", and staying abroad as "0". The sample for Model 5-3 is confined to foreign degree holders, and Model 5-4 only targets returnee scholars and emigrant scholars.

Table 5.12 Explaining return migration by 2006

Explanatory Variable	***Model 5-3***				***Model 5-4***	
	Specification I		***Specification II***			
Female (vs. Male)	0.419202		0.270645		2.381619	
Age	1.045856				1.178552	***
Cohort (Reference group = Pre-incident)						
Early-reform			1.982966			
Post-incident			2.096857			
Millennium			0.873406			
Class of university (Reference group = Class III)						
Class I	0.207488	***	0.167559	***	NA	
Class II	0.243811	***	0.26217	***	NA	
Class IV	1.96734		2.466619		1.712645	
Field (Reference group= Chemistry)						
Mathematics	1.134476		1.289872		0.307006	
Physics	0.70186		0.897422		0.99669	
Biology	1.228247		1.359157		0.248381	
Observation		159		159		122
Pseudo R^2		0.141		0.1539		0.1777

Note: *p<0.1, **p<0.05, ***p<0.01

Model 5-3 has two specifications, whose explanatory variables are the same as Model 5-2's (Table 5.10). Although most odds ratios of the control variables confirm our findings based on the descriptive analyses, they are not statistically significant probably due to the small sample size (N=159). For example, males are found to be more likely to return than females; old scientists are more likely to do so than young researchers; so are mathematicians and biologists relative to chemists. Mathematicians trained abroad were more likely to concentrate in prestigious universities than chemists, which might explain why the odds ratio between the two groups is larger than one, after we control for their university class of doctorates. These findings are not conclusive since they did not pass the statistical test.

Nonetheless, two dummy variables of university class, the variables of our focus, are highly significant. If the reference group is set as graduates from universities in Class III, the odds ratios of return for those in Class I and II were only one fifth or one fourth of that for the reference group. The odds ratio for those in Class IV was almost twice as high as that for Class III, but it is not significant largely due to the small number of observations. In addition, we used a multinominal logit model to examine the probability of location choices. It is well known that a high proportion of foreign S&E doctorates from developing countries stayed in the United States (Solimano 2001; Finn 2007), and our findings are consistent with the pattern. For Chinese scientists graduated from foreign Class-I institutions, their relative risk, or the ratio between probability of staying in the US and returning to China, was 8.7 times as high as that of the reference group; the relative risk of those graduated from Class-II institutions was 4.7 times higher.

The sample size of Model 5-4 (N=122) is even smaller than that of Model 5-3, and most of the independent variables are insignificant except the age factor. The positive effect of age reflects that young scholars were more likely to stay abroad in 2006 as post-docs or visiting scholars, who might have not finished their overseas visits. The odds ratio for females was 2.4, indicating that odds of returning to China for women scholars by 2006 was 1.4 times larger than that for males. Those scholars graduated from Class-IV universities in China were more likely to return than those from Class III (odds ratio = 1.7). But neither of the effects is significant. Additionally, the odds ratios suggest that emigrant scholars of mathematics and biology were more likely to stay in foreign countries than those of chemistry, which is consistent with the descriptive analysis.

As a subset of scientists with international experience, the observations of returnees only represent a small portion in our sample. Although we conclude that returnees, with foreign degrees or not, tended to be negatively selected from China's scientific diaspora, it is not clear whether the selectivity had been enhanced or weakened. We had run Model 5-3 with the data of 1998 and 2002, and tested whether the negative selectivity of return migration varied over time, but the results are so mixed and insignificant that it is difficult to draw a decisive conclusion. Hence our second hypothesis remains an open question.

Chapter 6 Explaining Research Performance and International Collaboration

After discussing the migration flows of Chinese scientists and their selectivity, we further analyze their research performance and major determinants in this chapter. Section 6.1 compares the differences of total research output between domestic and overseas scientists, and reveals their narrowing research gap. Section 6.2 reports our findings on returnee scientists' contributions to China's scientific production. Section 6.3 analyzes international collaboration between scientists in China and those in foreign countries, as well as its positive impact on the productivity level of domestic scientists.

6.1 Narrowing research gap

Has the brain drain of scientists led to rising inequality of research capacity between China and the host countries? In order to answer this question, we firstly compared the changing profiles of research output by Chinese scientists in China and outside China. The general trend is clear - the research gap between domestic scientist and their overseas peers did not widen between 1998 and 2006; rather, it had been narrowed dramatically. In that period, the total scientific production of domestic scientists substantially surpassed that of their overseas peers in terms of the number of publications, citations, and research output[51] (Table 6.1).

[51] The definition of research output can be found in Table 4.1.

China already had a quantitative edge as early as 1998, when domestic scientists published over seven hundred SCI-indexed articles while overseas scientists published nearly six hundred[52]. The former's publications grew by over three times after 1998 while the latter's increased by less than two times. The total citations received by domestic scientists were only 54.8% of those received by their overseas peers in 1998. However, the former received 25.9% more citations than the latter eight years later. The trend of research output was similar to that of citations, since the two indicators are closely associated. After rapid growth for years, China had dominated the research output of Chinese scientists at leading global universities in 2006, and represented nearly 60% (57.8%) of their global production.

Table 6.1 Total papers, citations and research output by region and year, 1998-2006

Year	***Publication***			***Citation***			***Output***		
	Domestic	*Overseas*	*Total*	*Domestic*	*Overseas*	*Total*	*Domestic*	*Overseas*	*Total*
1998	761	598	1359	2904	5302	8206	3554	5811	9365
%	56	44	100	35.4	64.6	100	37.9	62.1	100
2002	1798	1068	2865	11553	10462	22015	13774	11800	25574
%	62.7	37.3	100	52.5	47.5	100	53.9	46.1	100
2006	3327	1679	5007	19516	15505	35021	24992	18254	43246
%	66.5	33.5	100	55.7	44.3	100	57.8	42.2	100

Note: the non-percentage figures are estimated after weighting and rounded up to their units.

The inequality of knowledge production between emigrant scientists and those left behind had been reduced at national level, even though the selectivity of emigration became stronger over time. The major driving force behind the trend was not the growing research workforce in China but the rising average productivity of domestic scientists.

[52] Here the figures of publications and citations are adjusted by the number of authors to avoid double counting.

The average number of publications of mainlander researchers rose from 0.31 in 1998 to 0.83 in 2006, and they had caught up with their overseas peer (0.8) in this regard (Table 6.2). A domestic scientist received 4.84 citations on average in 2006, which already equaled two thirds (65.7%) of the average citation rate of the overseas group (Figure 6.1). Overall, the average output ratio between the two groups had increased from 24.3% in 1998 to 71.5% in 2006, indicating that domestic scientists had attained broad international visibility and scientific recognition in the world.

Table 6.2 Average paper, citation and research output of Chinese scientists by location and year, 1998-2006

Year	***Paper***		***Citation***		***Output***	
	Domestic	Overseas	Domestic	Overseas	Domestic	Overseas
1998	0.31	0.62	1.20	5.42	1.47	6.06
2002	0.58	0.64	3.75	6.26	4.47	7.06
2006	0.83	0.80	4.84	7.37	6.20	8.67

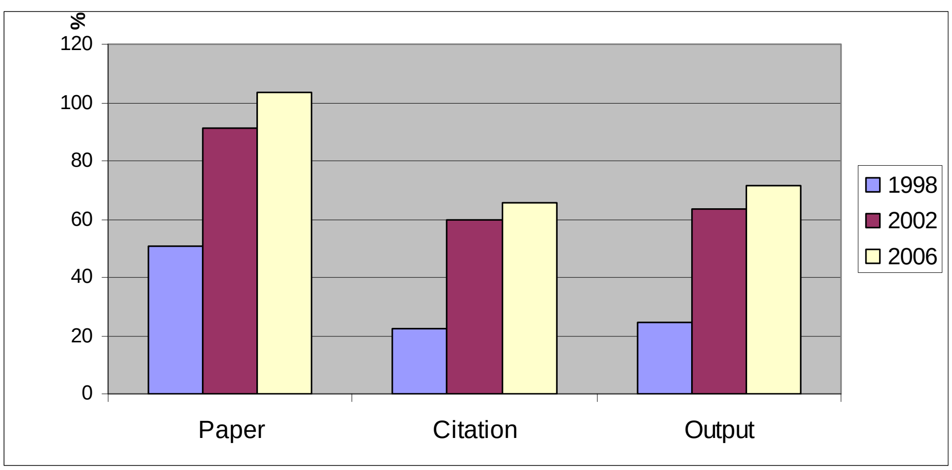

Figure 6.1 Ratio between the average indicators of domestic scientists and overseas scientists

The number of scientists at the eighteen top Chinese universities increased by 63.4% between 1998 and 2006, which was much less than the growth rate of overseas scientists (115%). A simple decomposition shows that the growth of domestic research output largely resulted from rising productivity (54.6%). The increase of research personnel only contributed 10.8%, and the product of the two factors, or the growing productivity of new researchers, contributed the remaining one third (34.7%). By contrast, manpower expansion was the most important source of the research output growth for overseas Chinese (55.4%) and productivity gain only caused 20.8% of the growth.

Each of the four broad fields made substantial progress in China despite disciplinary differences (Table 6.3). The total output of chemistry experienced a tenfold growth during the period; the output of mathematics and biology also increased by six and seven times, respectively; the growth rate of physics was the lowest, but its output tripled. In terms of per capita productivity growth, the four fields were in the following order from high to low: chemistry, biology, mathematics, and physics. The low growth rate of physics was largely caused by its relatively high level of production in 1998.

Table 6.3 Total and average output of domestic scientists by discipline and year, 1998 - 2006

Year	***Mathematics***		***Physics***		***Chemistry***		***Biology***	
	total	*average*	*total*	*average*	*total*	*average*	*total*	*average*
1998	419	0.88	1997	3.01	880	1.05	258	0.59
2002	835	1.17	3687	4.59	4927	4.52	221	0.48
2006	2993	3.44	7138	6.92	10817	7.62	2044	2.95

One may question whether China's scientific advancement in the observation period was actually a proliferation of mediocre research papers, though the average quality of these papers was improving. We can solve this puzzle by examining the two indicators, highest individual performance and highest team performance, which refer to the number of citations received by one's most cited paper in a given year[53]. We chose to observe the 75th percentiles of the two variables for the purpose of comparison, as they represent the middle performance level of the upper half Chinese scientists in term of productivity. For example, the 75th percentile of the individual indicator for domestic scientists is 2.67 for 2006, which roughly means the highest performance of three quarters of the domestic group was below the score, while that of the rest was above it.

Table 6.4 75th percentile of highest individual and team performance by region and year, 1998-2006

Year	*Individual highest performance*			*Team highest performance*		
	Domestic	Overseas	ratio	Domestic	Overseas	ratio
1998	0.33	2.5	13.2%	1	7	14.3%
2002	1.50	4.5	33.3%	4	15	26.7%
2006	2.67	4	66.7%	13	17	76.5%

Note: ratios are calculated as domestic figures divided by overseas ones in each row.

The results presented in Table 6.4 show a clear pattern of convergence. With regard to the individual indicator, the ratio between domestic and overseas scientists increased to 66.7% in 2006, while it was just 13.2% in 1998. Correspondingly, the ratio of the team indicator also grew dramatically from 14.3% to 76.5%. Both of the big jumps indicate that scientists in China became more capable of conduct high-quality research

[53] The definitions of the two indicators can be found in Table 4.1.

comparable with the achievements of overseas Chinese, and they became more likely to participate in important projects over time. We may use different counting methods to weight the highly cited publications, but the patterns of convergence would be similar.

Table 6.5 Geographic distribution of population and output of prolific scientists by discipline, 2006 (%)

Discipline	*Scientist*				*Output*			
	China	*ROW*	*US*	*Total*	*China*	*ROW*	*US*	*Total*
Mathematics	39.5	43.3	17.2	100	52.3	28.1	19.5	100
Physics	61.3	15.1	23.6	100	58.3	12.4	29.4	100
Chemistry	57.3	19.4	23.4	100	54.7	13.5	31.8	100
Biology	43.4	4.3	52.3	100	32.9	3.1	64.0	100

An examination of the total research output of prolific scientists further supports our findings on this trend. There are many definitions of highly productive scientists in the literature, and here we operationally define a “prolific scientist” as a scientist whose output in 2006 was beyond the 75th percentile of individual output among all the Chinese scientists in his field. The distribution of these scientists across regions enables us to compare their scientific excellence. We find that, compared with the geographic distribution of all Chinese scientists, prolific scientists tend to concentrate geographically in the host countries, particularly the United States, which is consistent with previous studies on elite scientists (Laudel 2005; Zucker and Darby 2007). For example, 23.4% of all prolific chemists resided in the US in 2006, while only 14.8% of all Chinese chemists worked in that country (Table 6.5). It is more impressive to observe that one out of two prolific Chinese biologists (52.3%) stayed in the US. However, the US hosted less than twenty percent (17.2%) of prolific mathematicians and 43.3% of them lived in the ROW in 2006.

We further evaluated the relative performance of prolific scientists in China by comparing their percentage share of the population and with their share of the global output. For example, the share of the output by prolific physicists in China (58.3%) was lower than their share of the population (61.3%), the difference being only three percent. Thus also the case of chemistry. Biology is the one major area where China has lagged behind. Researchers in China represented 43.4% of all prolific biologists, but they only contributed one third (32.9%) of the total research output by this type of scientists. The words of a scientist studying health science confirmed this finding: “Even with a growing number of Chinese contributors, the mainland scholars are quite limited as the contributors as overseas Chinese in the western academes (Welch and Zhang 2008, 531).” By contrast, prolific mathematicians in China outperformed their overseas counterparts, as they produced over half (52.3%) of the global research output in their field, and they only represent 39.5% of the population in this field. The research excellence of domestic mathematicians seems counterintuitive, since Chinese mathematicians had the highest rate of brain drain and overseas mathematicians tended to graduate from more prestigious universities. Students of migration may study this puzzle in the future by closely examining the dynamics in this field.

6.2 Contribution of returnees

China has adopted a variety of measures to enhance its research capacity in recent years. First of all, its R&D budget has risen at a double digit rate since the late half of the 1990s. The Chinese government has invested a great deal since launching the 211 Project (NPC, MOE, and MOF 2005). For example, the two top universities in China, Peking University and Tsinghua University, were selected to be intensively funded by the Ministry of Education (Huang, Varum, and Gouveia 2006). Secondly, the National Natural Science Foundation of China (NSFC) was established to manage the national funding for basic research by a merit-based evaluation mechanism (Xue 1997). Its annual budget and the number of applicants increased significantly in the past decade.

Besides the funding increase and institutional reform, growing research personnel in China, particularly those with overseas experience, contributed enormously to the national scientific enterprise. Table 6.6 shows the annual total output of domestic scientists in the three observation years. According to the bibliometric data we collected, the participation of returnee scientists in China's scientific production became more important over time. The share of returnees' contribution in the domestic publications increased constantly from over a quarter (26.9%) to over a half (58.9%) between 1998 and 2006 (Table 6.6). Their shares in total citations and research output remained stable around the level of 35% between 1998 and 2002, but they jumped to nearly two thirds in 2006.

A disaggregation of the global output reveals that returnee scholars were the major driver in reducing the international research gap between domestic and overseas scientists. Their output represented almost a third (31.9%) of the global scientific production by Chinese scientists in 2006 (Table 6.7), which had caught up with the share of emigrant students (33.9%). The stagnation of all returnees' relative contribution in 2002 (see Table 6.6) mainly resulted from the underperformance of returnee students. There are only 33 observations of returnee students in our sample, the smallest of all the five migration types. Hence the findings based on them might suffer from selection bias and measurement errors. It is still fair to say that we find no significant contribution of returnee students, which is consistent with other scholars' concern that China attracted mostly second-rate talent from abroad (Zweig 2006). In addition, the share of stayers' contribution remained over 20%, and it once rose to 34% in 2002, largely because emigrant students' portion decreased to 39.6% in that year.

Table 6.6 Total publications, citations and research output of domestic scientists by migration group and year, 1998-2006

Year	*Publication*			*Citation*			*Output*		
	stayer	*returnee*	*total*	*stayer*	*returnee*	*total*	*stayer*	*returnee*	*total*
1998	556	205	761	1818	1086	2904	2277	1277	3554
%	73	26.9	100	62.6	37.4	100	64.1	35.9	100
2002	975	823	1798	7612	3940	11553	8830	4944	13774
%	54.2	45.8	100	65.9	34.1	100	64.1	35.9	100
2006	1369	1958	3327	6926	12590	19516	9204	15788	24992
%	41.1	58.9	100	35.5	64.5	100	36.8	63.2	100

Table 6.7 Distribution of total research output by migration type and year

Year	*Stayer*	*Returnee student*	*Returnee scholar*	*Emigrant student*	*Emigrant scholar*	*Total*
1998	2277	419	858	5453	358	9365
%	24.3	4.5	9.2	58.2	3.8	100
2002	8830	553	4391	10122	1678	25574
%	34.5	2.2	17.2	39.6	6.6	100
2006	9204	1992	13796	14648	3606	43246
%	21.3	4.6	31.9	33.9	8.3	100

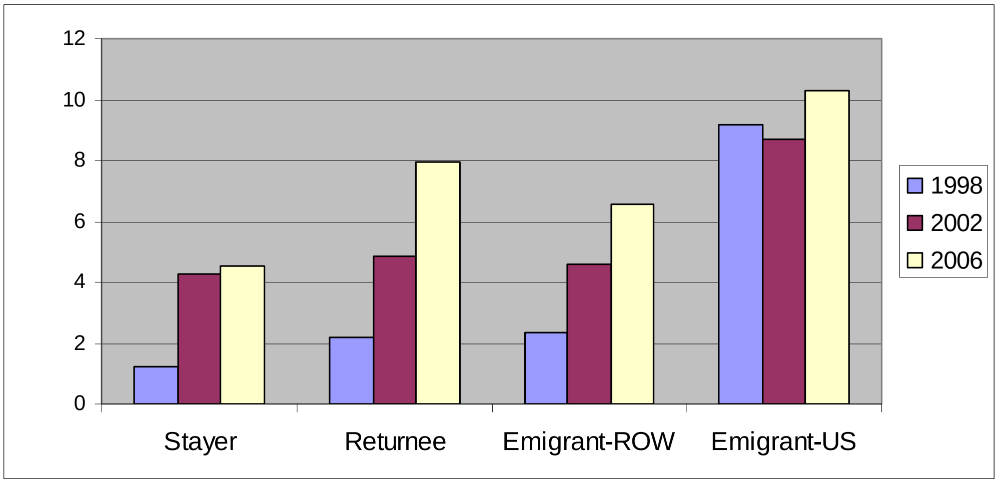

Figure 6.2 Average research output by migration group and year, 1998-2006

Some may wonder whether the expanding share of returnees was mainly driven by population growth, as many stayers became returnees by definition after staying overseas for two or three years. While the demographic shift was undeniably a part of the story, the productivity growth of returnees was equally important. The average research output of returnees had constantly increased from 2.2 points in 1998 to 7.9 in 2006 (Figure 6.2), while that of stayers dramatically rose to 4.28 by 2002 and remained stable until 2006. It is not clear why returnees outpaced stayers in terms of productivity growth in the late half of the period, but more overseas experience certainly played an important role. The average output of returnees grew so rapidly that it already surpassed that of emigrants in the ROW in 2006, and greatly narrowed its gap with that of emigrants in the US. The ratio of the average output between returnees and emigrants in the US increased from a quarter (24%) to three quarter (77.2%) in the observation period. In addition, returnees were ranked well above stayers and slightly below emigrants in the ROW in terms of the 75th percentile of their individual highest performance in 2006.

Returnees' research advantage over stayers differed considerably by cohort. The younger the cohort, the less the advantage that the returnees had. The total output of returnees in the early-reform cohort was almost four times that of stayers in 2006, while the output ratio between the two groups within the millennium cohort is only 0.48, indicating that the youngest returnee scientists made the least contribution to China relative to their stayer counterparts (Table 6.8). Similarly, the ratio of average output between returnees and stayers dropped greatly from the oldest (2.67) to the youngest cohort (0.68). The average output of returnees changed substantially from 11.2 of the early-reform cohort to 3.34 of the millennium cohort, while that of stayers varied slightly around 4.6 points across cohorts. This trend of bifurcation might reflect an age effect, as older returnees tended to have more cumulative advantage over stayers over the course of their research careers. It might also reflect a cohort effect, as younger cohorts of stayers were more likely to catch up with returnees of similar age than older ones. Due to the short period of our observation, the sample does not allow us to conduct a longitudinal analysis and disaggregate the two effects here.

Table 6.8 Total and average research output by cohort and migration group in 2006

Cohort	***Total output***			***Average output***		
	Stayer	*Returnee*	*Ratio*	*Stayer*	*Returnee*	*Ratio*
Early-reform	1266	5005	3.95	4.19	11.20	2.67
Pre-incident	2054	5661	2.76	5.10	10.52	2.06
Post-incident	3045	3775	1.24	4.15	6.49	1.56
Millennium	2727	1307	0.48	4.89	3.34	0.68

Note: the column "ratio" shows the ratios of total or average output between returnees and stayers in each cohort.

In addition, we examined the disciplinary differences and found that returnee scientists made a larger contribution in physics and biology. The total output of returnees was 3.7 times as high as that of stayers in physics in 2006, and the ratio of output between returnees and stayers in biology was 2.2. The former case is understandable since there are more returnees proportionally in physics than in any other field. The latter case can be explained by the large performance gap, as the average output of returnee biologists was 1.3 times higher than that of their stayer colleagues. The distribution of prolific scientists in each field is consistent with these findings. Although prolific scientists concentrated disproportionally in the group of returnees in each discipline, they were far more likely to be identified as returnees in physics and biology. For example, returnee scientists represent a half (49.4%) of all domestic biologists, but nearly nine out of ten (87.3%) prolific biologists in China were returnees.

As Section 3.1 mentions, empirical regularities of individual research productivity can be described by power laws (Lotka 1926). As distributions of bibilometric data, either publications or citations, they exhibit extreme skewness. For example, a quarter (25.1%) of Chinese scientists in our sample did not publish any SCI-indexed paper in 2006, while the top 24.5% productive scientists accounted for 82.5% of the citations. Hence outstanding researchers have a significant impact on statistical properties of the entire distribution, and average output is not adequate for comparing scientific performance at the group level.

In order to fit the skewed bibliometric indicators and systematically investigate the productivity premium of return migration, we utilized negative binomial regression on the output data, which has been adopted by previous studies (e.g. Allison 1980; Song, Almeida, and Wu 2003). A negative binomial model is advantageous for estimating occurrences of an event, such as citation counts in a given period. Although research output by our definition is not an "event" in a strict sense, it has been transformed into a count variable truncated at zero[54]. Poisson models are also well known to deal with count data, but it assumes equality of mean and variance of the dependent variable. This is not true for our data where the variance of research output far exceeds its average[55]. It is more appropriate to use negative binomial models, as it accounts for the skewness of the data and allows overdispersion. As a drawback, conclusions based on a negative binomial model may be less precise because the estimated standard errors tend to be larger than those based on an alternative Poisson model[56].

We first regressed the research output of domestic scientists in 2006 on a vector of individual factors in Model 6-1. This model has two specifications, whose explanatory variables are specified in Table 6.9, as well as their incidence rate ratios and statistical significances[57]. To control for the effect of overseas experience, the model includes a

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[54] See the definition of the variable "*output*" in Table 4.1.

[55] For example, the variance of the output in 2006 is 26.8 times as much as its mean.

[56] Another issue of using negative binomial model is whether there are excess zeros in the dependent variable. For example, a scientist did not publish any research if he was on a sabbatical leave in 2006. However, his case is different from those who didn't publish because of low productivity. Excess zeros occur when a scientist produces no output for reasons irrelevant to his research skill. We have run a zero-inflated negative binomial model, and find that its advantage over a standard one is not statistically significant (p-value of the Vuong test > 0.5), which means there are not many excess zeros of the dependent variable.

[57] The regression analysis here assumes that publications in a given year were produced in the corresponding academic year. However, this is not necessarily the case, depending on the cycle of publication. The cycle from submission to formal publication can vary considerably by discipline, journal, and project. However, the assumption would not cause a big mismatch, as most authors did not shift job or

variable of migration status (returnee vs. stayer). The class of one's working affiliation is included to control for research environment (the Class III vs. Class IV)[58]. We also considered introducing the variable of doctoral education, but it is highly correlated with that of work affiliation, as graduates from universities at a certain level are likely to find research jobs at the same level. The second specification adds two new explanatory variables, professional status and administrative position, whose dummy variables and reference groups are given in Table 6.9. As age and professional status are highly correlated (r = 0.66), we exclude age from the model as its effect is insignificant and has little explanatory power.

Table 6.9 Explaining research output of domestic scientists in 2006

Explanatory Variable	***Incidence rate Ratio (Model 6-1)***			
	Specification I		***Specification II***	
Female (vs. Male)	0.5093987	***	0.54979	***
Field (Reference group= chemistry)				
Mathematics	0.4018623	***	0.4055352	***
Physics	0.7386365		0.71491	
Biology	0.3052621	***	0.3074561	***
Class of affiliation (Reference group = Class IV)				
Class III	1.359974	*	1.329673	*
Returnee (vs. Stayer)	1.431712	**	1.175481	
Professional status (Reference group = associate professor)				
Doctoral student / postdoc			1.755119	**
Assistant professor			1.16285	
Full professor			1.841094	***
Administrative position (Reference group = no position)				
Center/committee director			2.614397	***
Dean/assistant dean			1.726424	**
Observation		256		251

change title in a given year.

[58] The definitions of Class III and IV can be found in Page 90.

Pseudo R^2	0.0352	0.0629

Note: *p<0.1, **p<0.05, ***p<0.01

For easy interpretation, we have transformed the coefficients of the independent variables into incidence rate ratios, which compare the rate of events occurring at a given point or period. The incidence rates in Model 6-1 actually refer to the annual productivity rates of Chinese scientists in 2006. The results of three control variables, including gender, field and affiliation, appear very similar in the two specifications. Female scientists were nearly 50% less productive than males, as we anticipated in Section 4.3. Mathematicians and biologists appeared far less productive than chemists, but the disparities actually reflect different publication and citation practices by discipline, rather than real productivity gaps (Lewison and Dawson 1998; Klamer and Van Dalen 2002). Podlubny (2005) even estimates that "one citation in mathematics roughly corresponds to 15 citations in chemistry, 19 citations in physics, and 78 citations in clinical medicine."

The effects of other factors can be estimated more precisely after controlling for the disciplinary differences. Working in research institutions in Class III boosted one's productivity by a third relative to working in those in Class IV, and the effect is significant at the level of 90%. The advantage of working in more prestigious universities may result partly from higher skill level of faculty members and partly from more conducive research conditions.

Surprisingly, associate professors in China, as the reference group, had the lowest productivity (see the second specification). Although assistant professorship had an insignificant effect on one's productivity, doctoral students/postdocs and full professors were 75.5% and 84.1% more productive than associate professors, respectively. Both of the results are highly significant and robust even after we excluded outliers with the highest output from the sample. Here we may hypothesize that those with lower professional status had more updated knowledge structures than associate professors, and full professors controlled more academic resources than associate professors. It is also possible that some associate professors could not get promoted to full professorship, so they were less active than either young assistant professors or old full professors. The detailed reasons behind the differences need further research. The effects of taking administrative positions are also highly significant, as directors of research centers/committees exhibited 1.6 times higher productivity than those without positions. Department deans or assistant deans were 72.6% more productive, though their administrative duties might take a considerable amount of working time.

Returnees were 43.2% more productive than stayers according to the result of the first specification. The former's advantage drops to 17.5% and becomes insignificant, however, after we control for professional status and administrative position. This difference between the two specifications reveals that the advantage of returnees might lie in their ability to take higher professional positions and assemble more academic resources. In addition, returnee students were far less productive than returnee scholars using a similar regression model, possibly because the latter were more successful than the former in exercising and nurturing their skills after reentering the research environment in China.

In order to examine the qualitative dimension, the second negative binomial model (Model 6-2) regressed individual highest performance of domestic scientists in 2006 on the selected predictors (Table 6.10)[59]. The results of its two specifications look similar to those of Model 6-1. However, we find no significant difference between returnees and stayers in either of the specifications, though the descriptive analysis shows that the 75th percentile of the former's highest performance was much higher than the latter's. Returnees' contribution to research quality of the domestic community seems less clear than their contribution to total output.

Table 6.10 Explaining highest performance of domestic scientists in 2006

Explanatory Variable	*Incident Rate Ratio (Model 6-2)*			
	Specification I		***Specification II***	
Female (vs. Male)	0.558925	***	0.565786	**

[59] Negative binomial regression generally requires count data (each value is an integer), but it also allows modeling of non-integer numbers with decimal places (Hilbe 2008). The values of highest performance are not rounded up here.

Field (Reference group= chemistry)				
Mathematics	0.459554	***	0.461995	***
Physics	0.793994		0.768634	
Biology	0.444578	***	0.426877	***
Class of affiliation (Reference group = Class IV)				
Class III	1.460566	**	1.468923	**
Returnee (vs. stayer)	1.279857		1.152202	
Professional status (Reference group = associate professor)				
Doctoral student/postdoc			2.365861	***
Assistant professor			1.484832	
Full professor			1.500942	*
Administrative position (Reference group = no position)				
Center/committee director			2.011994	***
Dean/assistant dean			1.672508	**
Observation		256		251
Pseudo R^2		0.0382		0.0639

Note: *p<0.1, **p<0.05, ***p<0.01

It is also notable that the advantage of working at Class III universities becomes more substantial and significant in Model 6-2 than in Model 6-1. As governmental investment in higher education is unequally distributed, outstanding studies often come from the most prestigious universities in China, though more mainland scholars have begun to publish articles in SCI-indexed journals. In addition, doctoral students and post-docs exhibited higher individual performance than those with other professional status, indicating that the new generation of scientists in China has acquired stronger research capability.

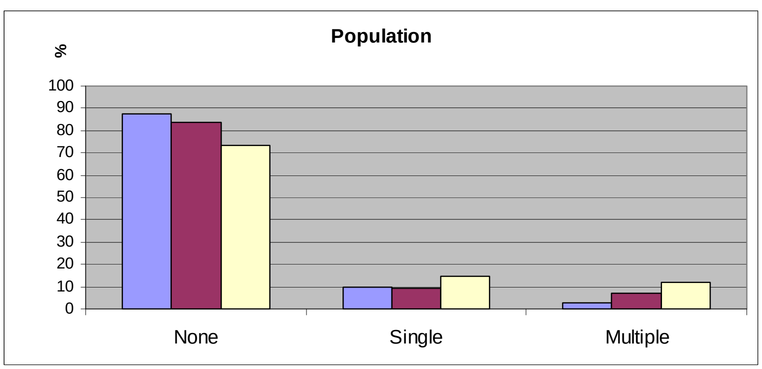
6.3 Propensity and impact of international collaboration

In addition to the benefits brought back by returnees, the scientific diaspora's contribution to their home country can also be enormous. Some sending countries have increased their interest and provided opportunities for expatriate scientists to develop professional connections with their domestic peers (Meyer and Brown 1999). The effects are still poorly understood. However, as Lowell and Gerova (2004) conclude, "Striking the right balance between a sending country's engagement in making use of its expatriate communities and the wishes and needs of such communities has yet to be found".

According to a new concept of "S&T human capital" raised by Bozeman et al. (2001), a scientist's research ability combines an "expanded notion of human capital" with a "productive social capital network". From this perspective, international research collaboration is often regarded as an effective way to get access to cutting-edge scientific knowledge and technologies for scientists in developing countries. Joint research with foreign colleagues is an important means to achieve high quality publications, rather than an indicator of high quality. As a response to the lack of study in this regard, this section depicts the characteristics of international collaboration of Chinese scientists, and then tests whether collaboration with foreign researchers raised the productivity level of domestic scientists.

We first categorized all domestic scientists into three groups according to the number of one's internationally coauthored papers in a given year. Those who published none, one, or at least two such papers are designated as "none", "single", and "multiple" in Figure 6.3, respectively. Overall, the proportion of scientists who coauthored internationally for at least one paper rose from 12.5% in 1998 to 26.8% in 2006, indicating their increasing integration into the international scientific community. This finding is consistent to some extent with one recent bibliometric study (Jonkers 2010,

Table 6.1), which reports that around a quarter of the SCI-indexed publications in China were co-published with foreign-based researchers between 1996 and 2005. The proportion of those with two or more internationally coauthored papers grew from only 2.7% to 12%, which reflects that transnational collaboration had became a normal practice for some researchers in China in the period. Domestic authors with international collaboration made the majority of contribution to China's SCI-index publications between 1998 and 2006, as their output represented around 60% of all the domestic scientific production[60]. The importance of international collaborators had slightly declined after 2002, probably because stayers had caught up with them in terms of individual productivity.



[60] Here the proportion of 60% is probably overestimated, as we assign equal share to each author of a joint research paper. A domestic scientist's output should be given less points, if he only plays marginal roles in international collaboration.

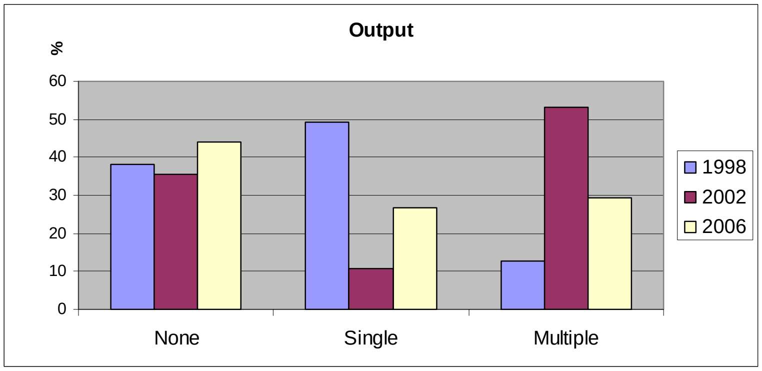


Figure 6.3 Total population and output distribution of domestic scientists by year and collaboration status

A large portion of the internationally coauthored papers by mainland scientists were actually produced by transnational Chinese research teams. Table 6.11 presents the population of domestic scientists who collaborated internationally and those who collaborated only with overseas Chinese for at least one paper[61], as well as their average output. The two groups are designated as "international" and "Chinese" in Table 6.11, respectively. The size of both groups had increased by several times according to our estimation, and those collaborating with overseas Chinese grew even faster. As a result, they represented half of all the international collaborators in China in 2006, which means one out of two international collaborators in China had jointly conducted research only with overseas Chinese scientists. More importantly, the average output of international collaborators was constantly much higher than that of non-collaborators, as the former were self-selected or chosen by their foreign colleagues to conduct joint research. The largest productivity gap between them occurred in 2002 partially because of outliers. It

[61] Please refer to the definitions of two variables "*intercol*" and "*cncoll*" on 4.1.

remained substantial after we excluded the outlier observations. Since international collaboration helped raise the productivity level of scientists in China, the loss of its scientific human capital was partially offset by the opportunity to gain through the diaspora networks.

Table 6.11 Population and average output of domestic scientists by year and collaboration partner, 1998-2006

Year	*Population*			*Average output*		
	International	*Chinese*	*Ratio (%)*	*None*	*International*	*Chinese*
1998	300	90	30	0.64	7.32	6.13
2002	500	220	44	1.90	17.77	29
2006	1080	540	50	3.73	12.96	10.13

International collaboration, by definition, involves domestic and overseas collaborators. It is also revealing to analyze the demographic profile of emigrants who collaborated with China in foreign countries. Many Asian scientists in the United States are found to maintain close academic linkages with researchers and institutions in their home countries (Choi 1995). Here we designate overseas Chinese scientists who jointly published at least one paper with domestic scientists in a given year as “collaborator”, and those who did not as “non-collaborators” (Table 6.12). The proportion of collaborators remained small between 1998 and 2006, but it had increased considerably from 9.6% to 20.2%, which helps explain the increasingly important role of overseas Chinese in establishing scientific collaboration between China and partner countries (Jonkers 2010, Section 6.5). The average output of collaborators was particularly high in 2002 and 2006 (15.8% and 17%, respectively), while that of non-collaborators was just over 6 points. The high ratios between the two indicators reflect the fact that productive overseas scientists were more likely to collaborate with their domestic peers than less productive ones.

Table 6.12 Population and average output of overseas scientists by year and collaboration with China, 1998-2006

Year	***Population (%)***			***Average output***		
	Non-collaborator	*Collaborator*	*Total*	*Non-collaborator*	*Collaborator*	*Ratio*
1998	90.4	9.6	100	6.1	5.4	0.88
2002	90.2	9.8	100	6.1	15.8	2.60
2006	79.8	20.2	100	6.6	17	2.59

Note: Figures in the column "ratio" are calculated as average output of collaborators divided by that of non-collaborators in a given year.

Scientists in China have unequal opportunities to get involved in international collaboration, just as they have different emigration prospects. We used logistic regression to reveal the effects of selected predictors on international collaboration propensity. Model 6-3 examines the likelihood of internationally joint publications by domestic scientists with different backgrounds. The dichotomous dependent variable is coded as "1" if one published at least one paper with a foreign author in 2006, and as "0" if not. Besides the explanatory variables introduced in the previous sections, the two specifications of Model 6-3 also include the location of one's doctoral degree (in China vs. outside China) and one's overseas duration by 2006 (Table 6.13). The second specification further adds research output in 2002 to the model. The dummy variables of discipline are excluded because their effects are found to be highly insignificant and have little explanatory power.

Table 6.13 Explaining international collaboration propensity of domestic scientists in 2006

Explanatory Variable	Odds Ratio (Model 6-3)			
	Specification I		Specification II	
Female (vs. Male)	1.352714		1.470144	
Class of affiliation (Reference group = Class IV)				
Class III	1.578302		1.267969	
Professional status (Reference group = associate professor)				
Doctoral student/postdoc	1.16769		NA[2]	
Assistant professor	1.419017		1.962899	
Full professor	1.535294		1.330932	
Administrative position (Reference group = no position)				
Center/committee director	1.157736		1.134639	
Dean/assistant dean	2.516794	**	2.634311	**
Location of doctorate (Reference group = in China)				
Outside China	0.291131	*	0.246808	**
Overseas duration	1.224624	***	1.236771	***
Research output in 2002			1.04016	*
Observation		238		203
Pseudo R^2		0.0761		0.098

Note: 1. *p<0.1, **p<0.05, ***p<0.01

2. There is no observation of this value in the sample chosen for Specification II.

We find no significant gender effect on international collaboration, though the odds for females were about 40% higher than males in 2006. Faculty members working at Class III universities were found to have a higher tendency of international collaboration than those in Class IV, though the result fails to pass the statistical test. The odds of international collaboration for full professors were 1.5 times as high as those for associate professors, while assistant professorship had a similar effect. No professional status is statistically significant. Nor does the effect of being center/committee director relative to taking no administrative position. However, deans and vice deans were far more likely to collaborate internationally than those with no positions, as the former's odds were 2.6 times higher than the latter's in the second specification. Surprisingly, a foreign doctoral background had a significant negative impact on one's likelihood of international collaboration - the odds for foreign degree holders were only a third of that for domestic degree holders. Despite selection bias due to the small sample size, it is possible that overseas students were more likely to return to China if they could not communicate smoothly with the scientific community in their host countries, thereby isolating themselves more from foreign researchers even more after their return. It also might be the case that many returnee students did not have opportunities to develop strong professional ties with foreign researchers, if they returned to China immediately after completion of their doctoral programs.

Last but not least, the likelihood of international collaboration was strongly associated with length of stay abroad. Chinese returnee scientists had become important transnational carries of social capital and they knew how to take advantage of their overseas experience. The longer a scientist lived in foreign countries, the higher the likelihood that he engaged in collaborative activities with foreigners in 2006. The effect is both substantial and highly significant, as one additional year of overseas duration could raise the odds of international collaboration by 22%. The result is robust even after we control for the research output in 2002 in the second specification. The second specification also shows that high productivity is a sound predictor of later international cooperation. Since more productive scientists in China might be prone to attend international conferences and visit foreign institutions, they probably had developed denser international academic networks, which facilitated their joint research with foreign researchers.

The factors determining the likelihood of collaboration with China for overseas scientists are quite different from those determining international collaboration for domestic scientists. Model 6-4 regressed a binary variable on a group of explanatory variables, which is coded as “1” if an emigrant scientist published at least one paper with a mainlander colleague in 2006 (otherwise as “0”). The chance of collaboration with scientists in China is found to be strongly associated with professional status, and weakly linked to overseas duration (Table 6.14). As overseas duration is highly correlated with professional status ($r>0.7$), we excluded the former from the model.

We find no significant gender effect based on Model 6-4, though the odds for female scientists were slightly lower than males. Overseas physicists were much more likely to conduct joint research with their domestic colleagues, if we take biologists as the reference group. Overseas mathematicians and chemists also seemed more likely to do so than biologists, though their differences are not significant. We find no significant difference between working affiliations, except that those in Class IV were far less likely to collaborate with China.

Table 6.14 Explaining collaboration propensity with China of overseas scientists in 2006

Explanatory Variable	*Odds Ratio (Model 6-4)*
Female (vs. Male)	0.881165
Field (Reference group= Biology)	
Mathematics	1.984005

Physics	5.189511	***
Chemistry	1.541967	
Ranking of affiliation (Reference group = Class III)		
Class I	1.197481	
Class II	1.052269	
Class IV	0.129072	
Professional status (Reference group = associate professor)		
Doctoral student/postdoc	2.69983	
Assistant professor	3.826762	**
Full professor	26.62392	***
Administrative position (Reference group = no position)		
Center/committee director	4.46638	*
Dean/assistant dean	0.706485	
Location of affiliation (Reference group = ROW)		
United States	0.343438	**
Research output in 2006	1.03653	**
Observation		175
Pseudo R^2		0.2644

Note: 1. *p<0.1, **p<0.05, ***p<0.01

The most striking finding is the different collaboration propensity by professional status. The odds for full professors were nearly 27 times as high as those for associate professors, and the odds for assistant professors and doctoral students/postdocs were also higher. A scientist in Australia once expressed his impression that "mainlanders tended to collaborate with Chinese expatriate scholars of higher rank … perhaps a confirmation of the longstanding hierarchical quality in Chinese society …" (Welch and Zhang 2008, 528). However, it does not explain the lowest propensity of associate professors. We can only speculate here that associate professors on the one hand had much less exposure to scientists in China than full professors, as they were less likely to be visited by domestic scientists or invited to visit China. On the other hand, they might have less contact with researchers and institutions in China than junior overseas scientists, because international telecommunication and transportation were not very developed in their early careers in the host countries.

Research center and committee directors among overseas scientists were far more likely to conduct joint research with peers in China than those without such titles. Taking positions as dean or assistant dean had a negative effect on collaboration, which was sharply contrasted with the case of domestic scientists. Although Chinese media often report high-profile returnees from the United States, the odds of collaboration with China for emigrants in the US were only 34% of the odds for those in the ROW. The reason for the difference possibly lies in the geographic proximity between China and some regions of the ROW (e.g. Hong Kong and Singapore). Most importantly, we find that more productive overseas scientists exhibited a higher tendency of collaboration with China, which is consistent with the descriptive analysis based on Table 6.12.

Using the same negative binomial regression model, we further investigated the effects of international collaboration on the productivity of domestic scientists. As an expanded version of Model 6-1, Model 6-5 includes two additional variables indicating whether one collaborates with foreign authors or with Chinese emigrants in 2006. The results presented in Table 6.15 are largely consistent with those of Model 6-1 (see Table 6.9), except that the significances of several dummy variables have changed slightly. The variable of migration group is replaced with overseas duration, which helps improve the goodness of fit. Nonetheless, its effect is insignificant in either of the specifications.

Table 6.15 Explaining research output of domestic scientists by international collaboration in 2006

Explanatory Variable	*Incidence rate Ratio (Model 6-5)*			
	Specification I		*Specification II*	
Female (vs. Male)	0.535924	***	0.619192	**
Field (Reference group= chemistry)				
Mathematics	0.355492	***	0.452985	***
Physics	0.61742	**	0.677077	*
Biology	0.30255	***	0.363266	***
Class of affiliation (Reference group = Class IV)				
Class III	1.324493	*	1.092011	
Professional status (Reference group = associate professor)				
Doctoral student/post-doc	1.680454		1.792707	
Assistant professor	1.020537		1.001453	
Full professor	1.761261	*	1.796253	***
Administrative position (Reference group = no position)				
Center/committee director	2.407019	***	2.148031	***
Dean/assistant dean	1.537592	*	1.342231	
Overseas duration	0.974006		0.977887	
International collaboration	2.336862	***	1.513364	**
Collaboration with emigrants			1.96141	***
Research output in 2002			1.027174	***
Observation	238		205	
Pseudo R^2	0.0869		0.1063	

The results show that domestic scientists' productivity gain resulted in large part from international collaboration in general, and collaboration with overseas Chinese in particular. The first specification of Model 6-5 reveals that international collaborators were 1.3 times more productive than non-collaborators, other things being equal. The second specification adds collaboration with overseas scientists to the model, and its effect is highly significant even after controlling for international collaboration. Compared with those without such collaboration, domestic scientists who had collaborated only with overseas Chinese were 96% more productive, possibly because it is easier to communicate with people with the same cultural background.

It seems these findings convincingly support the fifth hypothesis raised in Section 2.3, but one may wonder whether the relationships were merely strong associations. The causal link could be reversed – productive scientists in China were more likely to engage in transnational collaborative activities, instead of the argument presented here. Since co-authorship does not reveal the independent contribution of each partner behind the collaboration, we can not deny such possibilities. However, we still prefer to theorize that domestic scientists were more likely to play supplementary roles, or at most associative roles, in international collaboration, given the substantial research gap between China and the developed world. After all, the two collaboration indicators remain significant after we controlled for research productivity of 2002. Our findings are consistent with Ma and Guan (2005), who observe that international papers by Chinese authors have notably higher average impact than the indigenous papers, and foreign collaboration contributes greatly to the improvement of the mainstream connectivity and international visibility. Liu (2001) also reports that returnees participating in the One Hundred Talents Program were more successful than stayer scientists partly because the former collaborated with foreign authors more efficiently than the latter.

Table 6.16 Explaining highest performance of domestic scientists by international collaboration, 2006

Explanatory Variable	*Incidence rate Ratio (Model 6-6)*			
	Specification I		*Specification II*	
Female (vs. Male)	0.562149	***	0.689512	
Field (Reference group= chemistry)				
Mathematics	0.422456	***	0.516323	***
Physics	0.654275	**	0.72922	
Biology	0.401334	***	0.396363	***
Class of affiliation (Reference group = Class IV)				

Class III	1.427445	**	1.230404	
Professional status (Reference group = associate professor)				
Doctoral student/postdoc	2.028506	**	2.945201	
Assistant professor	1.290812		1.33023	
Full professor	1.357919		1.566776	**
Administrative position (Reference group = no position)				
Center/committee director	1.913679	***	1.655027	**
Dean/assistant dean	1.472606	*	1.306453	
Overseas duration	1.004905		0.981596	
International collaboration	2.536157	***	1.785227	***
Collaboration with emigrants			1.834442	**
Research output in 2002			1.05103	***
Observation		250		205
Pseudo R^2		0.1028		0.1262

Finally, we regressed individual highest performance of domestic scientists on the selected predictors of Model 6-5. The results of Model 6-6 are similar to those of Model 6-5 (Table 6.16), while the former has more explanatory power than the latter according to their pseudo R^2. It is notable that international collaboration had more influence on individual highest performance than on their general productivity. According to the second specification of the two models, the academic achievement of domestic collaborators was 78% higher than that of non-collaborators in terms of individual highest performance, while the former's achievement was 51% higher than the latter's in terms of general productivity. The role of international collaboration seems to be more important in improving China's research quality than in raising its quantity of publications.

Chapter 7 Counterfactual Analysis and Policy Implications

Based on the previous empirical findings, this chapter further explores the dynamic consequences of skilled emigration by simulating some scenarios under different conditions. Section 7.1 estimates China's intellectual loss due to the emigration of its scientific talent. Section 7.2 predicts the impacts of Chinese scientists' movements on research output in China, the host countries, and the world, given different conditions. Section 7.3 discusses the prevailing "talent mercantilism" and the new pro-migration argument. The final section presents the policy recommendations based on the major findings of this dissertation.

7.1 Intellectual loss by emigration

A skilled emigrant can cause two kinds of loss to his home country – the loss of the direct education investment in the human capital embedded in him, and the loss of potential products he would produce without emigration. The alarming report by the British Royal Society already distinguished the two kinds of loss in the early 1960s: "The economic consequences of the loss to this country of the leadership and the creative contributions to science and technology which they would have made in the course of their working lives", are "much more serious" than the loss involved through the expenditure on the education of those scientists who are now working overseas. Salt

(1997) also points out that the developing countries might be at risk of losing the youngest, most able talent with the greatest potential in the most important disciplines for the future economic development of their home countries.

Considering the importance of the second kind of loss, we only estimated the intellectual loss caused by emigrant scientists, or the potential contribution they would have made if they stayed in China. The approach of counterfactual analysis adopted here follows Desai et al. (2009), who estimate the tax losses of skilled emigration by presuming that Indian immigrants in the US had remained in their home country. It should be noted that "emigrant scientists" here do not include "emigrant scholars" who obtained their highest degrees in China, because their overseas stays were mostly temporary by nature, and did not constitute a "brain loss" in a strict sense.

The simulation procedure has three major steps. Five demographic variables, including age, cohort, gender, field, and college tier, would not change wherever one had his doctoral education or found jobs[62]. As the first step, we used logit models to regress each of four location-specific variables (class of affiliation, professional status, administrative position, and international collaboration) on the five unchangeable variables with the 2006 data of domestic degree holders in China. This step helped us predict the probabilities of each value of the four variables given one's demographic background. For example, if a male chemist "Zhang" was 46 years old and graduated from a second-tier college, he would have a chance of a 75% chance to become a professor in China according to the predicted probability distribution of professional

[62] One's field might shift in his life course, but in most cases a Chinese college graduate would stick to his undergraduate major in his later career.

status. For another example, a male physicist “Wang” would have a 50% chance to take administrative positions if he was aged 52 years and graduated from a first-tier university.

If we suppose all emigrant students, or emigrant scientists with foreign degrees, stayed in China for study and work, what positions would they obtain? The second step assigned values to them according to their unchangeable demographic attributes. Given the probability distributions of the four location-specific variables, we assigned values to each emigrant student by a stochastic process. For example, an emigrant scientist has a chance of 75% to be assigned the value of “professor” in China, if he shares the same background with Zhang (see the above paragraph). Lower professional status could also be attributed to him with a probability of 25%. We repeated the stochastic process by ten times as the result of each round was more or less different from others. The average result arguably reflects the counterfactual situation more accurately than the prediction of any single round. The four location-specific variables were thus recoded for a total of 148 observations of emigrant students.

The final step adopted the regression function based on the first specification of Model 6-5 (see Table 6-15) to estimate the counterfactual research output by emigrant students in China[63]. It should be noted that the subsample for generating the regression function was confined to domestic degree holders in China. We substituted the real attributes (e.g. age) and predicted attributes (e.g. class of affiliation) of all emigrant students into the regression function, and predicted the research output of each of them in

[63] For simplicity, we did not include the variable of collaboration with overseas Chinese and output in 2002 in the prediction function.

2006[64]. We then adjusted the conditions and predicted the net intellectual consequences of China's scientific brain drain in seven hypothetical scenarios. Each prediction process was repeated by ten times to calculate the average results for every scenario.

Table 7.1 Estimated research output and impacts in four scenarios in 2006

Scenario	*Emigrant students*		*Replaced scientists*	*Impact (%)*		
	Real	*Estimated*		*China*	*Host countries*	*World*
Full employment	14648	9886	NA	39.6	-80.2	-11.0
Half employment	SAA	4870	NA	19.5	SAA	-22.6
Full replacement	SAA	9886	-8155	6.9	SAA	-29.9
Half replacement	SAA	SAA	-4336	22.2	SAA	-21.0

Note: SAA stands for "same as above".

The first scenario is based on two scenarios. First, China had enough R&D budget to offer jobs to all emigrant students and they were all employed in the research sector in China in 2006. And second, the degree of international collaboration of each domestic scientist remains the same as the reality. The first row of Table 7.1 presents the counterfactual output of emigrant students and the impacts on different regions. If all foreign degree holders in the host countries did not go abroad for study and work, their total research output in China would reach 9886 points, or 39.6% of the scientific production by domestic scientists in 2006. As the real output of emigrant students was much higher (14648 points), the host countries would lose about 80% of its gain from overseas scientists, and the remaining 20% would be contributed entirely by emigrant scholars. Overall, the world's research output in 2006 would drop by 11% in this scenario.

64 We employed the statistical software "STATA" to do the prediction automatically.

For easy interpretation, in the following paragraphs we present all the impacts in terms of the percentage change compared with the real situation.

The intellectual loss to China looks striking under the condition of full employment. However, not all overseas scientists would pursue a research career if they stayed in China. They might shift to other highly paid occupations, such as engineers or managers in multinational corporations. Assuming half of emigrant students would be employed in the research sector in China, we selected 50% of emigrant students randomly and redid the prediction. The result is exactly the same as our expectation: their potential contribution to China (4,870) is only half of the output in the full-employment scenario, which means their stay would raise China's total output by 19.5%. This finding implies that a scientific brain drain brings much less loss to the home country if it does not have abundant R&D expenditure. In the half-employment scenario, the potential reduction of output in the host countries would still drop by 80.2% compared with the real situation, while the global reduction would double compared with the full-employment scenario (-11% vs. -22.6%).

The presence of additional human capital would not simply increase the number of research scientists in China, those scientists might also replace others who were employed by the leading Chinese universities. Supposing the national budget was only enough to hire a certain number of the domestic researchers, we may further assume that emigrants would replace an equal number of domestic peers in such a scenario, since the former's academic ability was generally stronger than the latter's. In order to identify the replaced domestic scientists, we first calculated the proportion of replacement in each broad field[65], and then randomly selected those who were replaced from the domestic talent pool.

The simulation results show that the lost output of the replaced scientists (8,155) would be not far from the estimated total output of emigrant students (9,886). As a result, the net effect is significant but not substantial, as China's scientific production in 2006 would rise by only 6.9%. The global output would drop substantially in this scenario, however, since the size of the domestic talent pool would shrunk by over a quarter.

We can also imagine a similar scenario where national scientists were only partially in excess of research jobs in China. In this scenario, half of the emigrant students are assumed to replace an equal number of domestic scientists, while the other half would be employed as additional human resources. The last row of Table 7.1 shows that the lost output by the replaced scientists was only 4,336 points. China's scientific production would grow by one fifth (22.2%), while the global output would drop by 21%, which is similar to the half-employment scenario.

China would retain more research personnel without the scientific brain drain, but it would also miss many opportunities for international collaboration. Among all domestic scientists who collaborated with foreign authors in 2006, almost half of them chose overseas Chinese as their only international partners for a research project. The other half possibly collaborated with overseas Chinese and scientists of other ethnic backgrounds, which we can not tell based on the data. Hence it is not unrealistic to assume that the degree of international collaboration by scientists in China would decrease by 50%, if

[65] The proportion varies across fields from 71% in mathematics to 30% in chemistry, as Chinese scientists in the four fields had different emigration rates.

their overseas peers did not constitute the research diaspora by emigration.

After we reran the simulation based on this assumption, the full-employment scenario changes substantially as the estimated output of emigrant students drops from 9,886 to 7,971, and more importantly, the total output of domestic scientists also drops from 24,992 to 17,509 (see the first row in Table 7.2). As a result, China's total scientific production would only increase by 2%, even if its scientific manpower rose by a quarter. The research output by all Chinese scientists in the world would drop by a third (32.7%) in this scenario. In a similar scenario, the absence of overseas Chinese might also drive domestic scientists to establish more professional ties with foreign peers, which partially would compensate for the loss of international collaboration. If the degree of international collaboration by scientists in China decreased by only 25%, the total output in China would increase by 12.7%, and that in the world would decrease by 26.5% (see the second row of Table 7.2).

Table 7.2 Estimated research output at different levels of international collaboration

Scenario	***Emigrant students***		***Domestic scientists***		***Impact (%)***		
	Real	*Estimated*	*Real*	*Estimated*	*China*	*Host countries*	*World*
50% less collaboration	14648	7971	24992	17509	2	-80.2	-32.7
25% less collaboration	SAA	8811	SAA	19356	12.7	SAA	-26.5
Mixed conditions	SAA	6571	SAA	17849	-2.3	SAA	-35.2

Note: SAA stands for "same as above".

There can be a variety of combinations of employment, replacement, and international collaboration, which depend on our assumptions. We simulated the last scenario under a set of specific conditions: I. three quarters of emigrant students were employed in the research sector in China, and the remaining quarter shifted to other occupations; II. one quarter of emigrant students replaced an equal number of their domestic peers; III. international collaboration by scientists in China decreased by 25%. This scenario takes all the three conditions into account, and adjusts their effects to a moderate level. Its results show that China's total output would decrease by 2.3%, and the global production would drop by over a third (-35.2%). China's intellectual loss would turn out to be a "gain" in this scenario with mixed conditions.

The results of the above simulation indicate that China's intellectual loss would be substantial only under ideal conditions. When the employment of domestic research personnel was restricted by the national budget, China's loss due to the scientific brain drain would not be enormous, because the additional individuals either shifted to other occupations, or replaced other scientists. Less international collaboration would also reduce China's potential gain by retaining its emigrants. If the last scenario approximates the counterfactual situation more than the others, the scientific brain drain actually has little impact on China's total research output, while the global output would rise greatly, benefiting both the host countries and overseas Chinese scientists. The emigration of Chinese scientists was indeed a "Pareto improvement" in this sense, rather than an exploration by the host countries at the expenses of China.

7.2 Impacts of different migration scenarios

If China sent more students to foreign countries by 2006, most of them would probably stay abroad, but more returnees would come back. Their movement would have significant impacts on China, the host countries and the world. This section presents the simulation results of eight scenarios with different foreign education rates and return rates, which can help demonstrate the policy effects we will discuss later in this chapter.

Many factors influence the migration decision of overseas professionals – whether to return home or remain abroad (Gaillard and Gaillard 1997; Zweig 1995, 2006). This section does not focus on these determinants of migration; instead, its attempts to examine how the movements of Chinese scientists would influence the regional research output. We firstly considered two scenarios with hypothetical return rates. The return rate of foreign degree holders was 21.9% in 2006, and we raised this indicator by 10% in Scenario I-1 and lowered it by 10% in Scenario I-2. The simulation process is similar to that in Section 7.1, except that we adopted different subsamples for estimating probability distribution, assigning values and generating productivity functions.

A 10% higher return rate (31.9%) implies that 12.8% of emigrant students would return to China by 2006 besides those returnee students who already came back. In order to identify the additional returnees, we chose the given number of emigrant students randomly from the sample according to their expected probability of return[66]. Since the sample has only 33 observations of returnee students, we did not use them to generate the productivity function and thus avoided possible selection bias. As an alternative solution, we combined the foreign degree holders in China and the ROW into a subsample and ran the regression of individual output with it. It is reasonable to assume that the additional

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[66] The probability of return was predicted based on the second specification of Model 5-3 (see Table 5-12).

returnee students would perform similarly as those in the subsample, since the average output of returnees in China was very close to that of emigrants in the ROW in 2006 (see Figure 6.2). This solution not only offers larger population base for estimation, but also saves the procedure of value assignment. We can directly predict the output of the selected emigrants according to their attributes in the host countries. The simulation process was also repeated for ten times to calculate the average results.

The first row of Table 7.3 shows the predicted outcome of Scenario I-1. The domestic output would reach 26,034 points thanks to more returnees, while the overseas output would drop to 16,548. Compared with the real situation, a reverse flux of talent would indeed raise China's total output by 4.2% at the expense of the host countries (Figure 7.1). Overall, the global production of Chinese scientists would be reduced by just 1.5%, which results from the lower productivity of the additional returnees after repatriation. By contrast, some returnee students would stay abroad in Scenario II-2, whose rate is set at 11.9%. Fewer returnees would lead to a loss of 2.9% to China and a gain of 9.4% to the host countries, as the output of the additional emigrants would be higher in the host countries than in China.

Table 7.3 Estimated research output in four scenarios with one changed condition

Scenario	***Condition***	***Domestic output***		***Overseas output***	
		Real	*Simulated*	*Real*	*Simulated*
I-1	10% higher return rate	24992	26034	18254	16548
I-2	10% lower return rate	SAA	24262	SAA	19977
II-1	10% higher foreign education rate	SAA	22627	SAA	22883
II-2	10% lower foreign education rate	SAA	27812	SAA	14790

Note: SAA stands for "same as above".

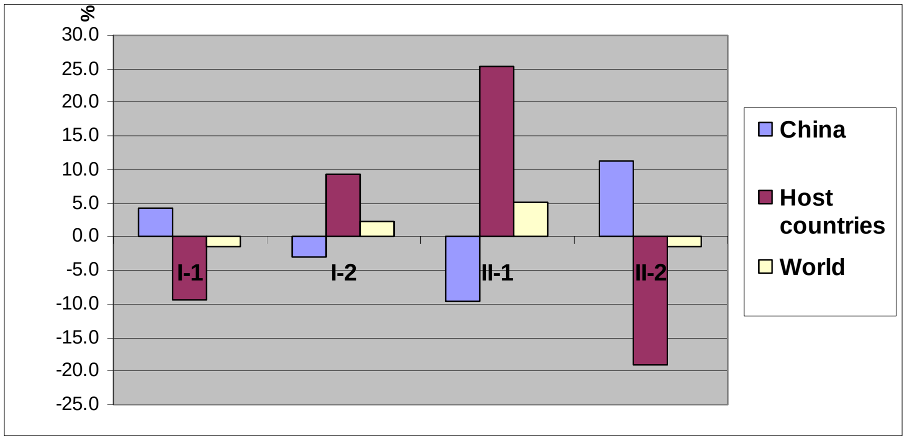

Figure 7.1 Regional impacts in four scenarios with one changed condition

Next we examined the impacts of different foreign education rates on the regional scientific production[67]. The foreign education rate of all Chinese scientists was 33.9%. We set this indicator at 43.9% in Scenario II-1 and at 23.9% in Scenario II-2. The simulation process of scenarios becomes more complicated, as 17.2% of the domestic degree holders are assumed to acquire foreign degrees by 2006, and 21.9% of them in turn would become returnee students[68]. Although more returnees would join the domestic research workforce, China would still experience a loss of 9.5% (see the third group of bars in Table 7.3), because the additional returnees would only be a small part of the newly added foreign degree holders. The host countries would benefit greatly (25.4%) from more overseas students, and the world would also gain by 5.2%.

In Scenario II-2, 37.8% of emigrant students are assumed to have domestic degrees, and 13.5% of them are further assumed to move abroad as emigrant scholars according to

[67] Here we did not choose emigration rate, because the indicator involves emigrant scholars and is more complicated.
[68] The calculation procedure is omitted here.

the emigration rate of domestic degree holders in 2006. In addition, 29.5% of returnee students in 2006 would remain overseas so as to keep the return rate at the level of 21.9%. We took all these demographic shifts into consideration, and each selected individual was randomly assigned values according to the likelihood of his academic status after relocation,[69] except that the average productivity of emigrant scholars was used to estimate the total output of the newly generated scientists in this group. The productivity functions for both sides were finally adopted to predict individual output.

As a result, China's output would rise by 11.3%, and the host countries' output would drop by 19%. The overall production in the world would decrease by only 1.5%, which is much smaller than the same indicator in Scenario II-1 (5.2%). The fundamental reason for this difference lies in the selection process based on the expected probabilities of foreign education[70]. The domestic scientists were positively selected to attend foreign doctoral programs in Scenario II-1, while the overseas scientists were negatively selected to stay in China in Scenario II-2. Hence the former's movement would lead to more significant outcome than the latter's relocation from a global perspective.

Only a single condition is changed in the above scenarios. It is more revealing to simulate scenarios with two conditions changed to estimate the combined effects of migration of scientists. Table 7.4 highlights four scenarios with certain return rates and foreign education rates. In the scenario of circulation, more Chinese graduates would get access to overseas education and more foreign degree holders would return to China, as

[69] Here academic status refers to the four location-specific variables (class of affiliation, professional status, administrative position, and international collaboration).
[70] The probability of foreign education was predicted based on the second specification of Model 5-1 (see Table 5-9).

both indicators are assumed to rise by 10%. The migration flows would lead to the scenario of exodus, if more left and less returned. By contrast, China would send fewer students abroad and lure more returnees back in the "engagement" scenario. The last scenario of isolation would occur, if both of the indicators dropped by 10%.

Table 7.4 Four scenarios with two changed conditions

		Return rate *(baseline=21.9%)*	
		10% Higher	*10% Lower*
Foreign education rate	*10% Higher*	Circulation	Exodus
(baseline=33.9%)	*10% Lower*	Engagement	Isolation

The simulation processes for the above four scenarios are similar to those for the previous four with single conditions changed, except that their demographic shifts differ by context. Table 7.5 presents the estimated outcomes of the four scenarios, and Figure 7.2 shows their impacts on different regions. China's total output would increase by the largest margin (11.9%) in the scenario of engagement, while it would reduce to the lowest point in the scenario of exodus. Correspondingly, the scientific production by overseas Chinese in the host countries would increase by 39.4% and decrease by 24.5% in the two scenarios, respectively. The other two scenarios, circulation and isolation, would affect regional outputs moderately, because the trend of foreign education and return flow counterbalanced the effects of each other. Chinese scientists in the world would make more contributions in the scenario "circulation" and "exodus", as more scientists moved abroad and exhibited higher productivity than their real level in China. By contrast, the global output would decrease in the other two scenarios, as those who are assumed to stay in China would outnumber those who moved abroad.

Table 7.5 Estimated research output in four scenarios with two changed conditions

Scenario	*Domestic output*		*Overseas output*	
	Real	*Simulated*	*Real*	*Simulated*
Circulation	24992	23321	18254	20672
Exodus	SAA	20558	SAA	25439
Engagement	SAA	27960	SAA	13778
Isolation	SAA	26507	SAA	16629

Note: SAA stands for "same as above".

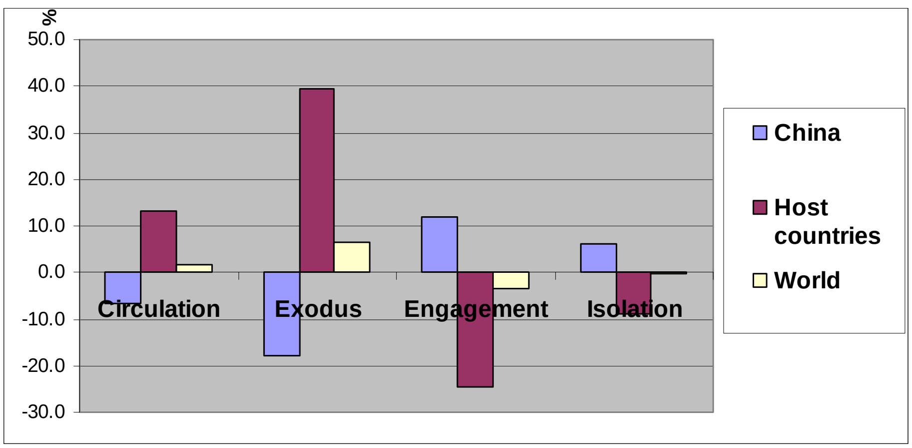

Figure 7.2 Regional impacts in four scenarios with two changed conditions

The above counterfactual analyses assume that international collaboration by domestic scientists did not change with the demographic shifts in any scenario, so as to simplify and stabilize the stochastic process of simulation. Next we adjusted the results in Figure 7.1 and 7.2 according to the estimated degree of international collaboration at the macro level, instead of predicting its values at the micro level. We first estimated the impacts of international collaboration at different levels on domestic total output by the simulation method used in Section 7.1. For example, the output decreases by 9.5% if international collaboration drops by 30%. In general, the former changes by 0.2%-0.4% as the latter changes by 1%, so we assume that the elasticity of domestic output with respect to international collaboration is one third, or 33.3%. In addition, the elasticity of international collaboration with respect to overseas personnel is assumed to be 50%. For instance, the international collaboration by domestic scientists will increase by 20%, if the number of overseas scientists rises by 40%. Table 7.6 presents the adjusted results in the eight scenarios based on these assumptions.

Table 7.6 Adjusted regional impacts in eight scenarios

Scenario	***China (%)***		***World (%)***	
	Simulated	*Adjusted*	*Simulated*	*Adjusted*
I-1	4.2	1.9	-1.5%	-2.8
I-2	-2.9	-0.9	2.3%	3.5
II-1	-9.5	-5.0	5.2%	7.8
II-2	11.3	4.3	-1.5%	-5.5
Circulation	-6.7	-4.7	1.7%	2.9
Exodus	-17.7	-11.4	6.4%	10.0
Engagement	11.9	4.8	-3.5%	-7.6
Isolation	6.1	2.4	-0.3%	-2.3

The effects of the adjustment are consistent in all the eight scenarios. The adjustment by international collaboration does not change the nature of the impacts, but affects their significance. The adjusted impacts on China are weaker than the unadjusted ones, while those on the world turn stronger. For example, the impact on China (-9.5%) in Scenario II-1 is reduced to -5% after adjustment, and that on the world is raised from 5.2% to 7.8%. The reasons are not difficult to detect. International collaboration partially compensates China's loss due to emigration of its scientists on the one hand; it mitigates China's gain on the other hand, if the country were to retain more research personnel or attract more returnees. Hence international collaboration counterbalances the change of domestic output. Since the impact on China and that on the world would always occur in opposite directions, the effects of international collaboration would naturally enhance the latter.

The simulation results presented in this section have strong policy implications, which are the focus of this dissertation. However, we need to discuss two representative views on skilled migration before we present the policy recommendations.

7.3 Talent mercantilism and the pro-migration argument

The competition for global talent is so fierce that people sometimes describe it as "the war for talent" (Michaels 2001) or "the battle for brainpower" (Wooldridge 2006). Many national policymakers are used to engaging in such rhetoric and tend to view skilled migration from a similar perspective of international trade balance. They often calculate "brain gain" or "loss" by simply counting the net intake of skilled migrants - a "national loss" occurs if skilled migrants moving to the country are less than those moving out from the country, otherwise a "brain gain" is cheered. For example, Canadian Prime Minister Jean Chrétien once stated that any brain drain from Canada to the United States has been more than offset by inflows of highly skilled Asians, and Canada is definitely a winner of "brain gain" (DeVoretz 2003). The simulation results in Section 7.2

show clearly that any changed condition leads to opposite effects on China and the host countries, as one side's manpower gain seems always at the expense of the other side's talent tool.

Facing this apparent zero-sum game, policymakers in the global talent race think like European mercantilists before the industrial revolution. Mercantilism is "an economic doctrine of the 16th and 17th centuries that international commerce should primarily serve to increase a country's financial wealth, especially of gold and foreign currency. To that end, exports are viewed as desirable and imports as undesirable…" (Sharma 2009, 117). As mercantilists believed that a nation's supremacy over other nations can be secured by accumulation of precious metal, today many scholars argue that a country can only maintain its competitiveness by expanding its talent pool.

Radical advocates of the "talent war" view brain drain as a problem in the same way as mercantilists viewed trade deficit. The policy implication of "talent mercantilism" is clear – a nation should retain their native talent and attract foreign talent so as to become a net importer of global skilled workers. For example, from a Canadian perspective, Devoretz (1999) suggests that "we urgently need policy that will both keep people from going to the US and persuade those who have already gone to come back," after he showed that the intake of immigrants from other countries could not counterbalance Canada's loss due to the emigration of its nationals to the US. Our findings also support such a view to some extent. China's national research output would increase mostly in the scenario of engagement, when it sent fewer students abroad and lured more returnees back home. By contrast, the host countries would maximize their gains from Chinese talent inflow in the scenario of exodus. Nonetheless, talent mercantilism is misleading since it ignores some important benefits of international skilled migration.

First, the global race for talent is not necessarily a zero-sum game. As free trade improves the mutual benefits of two countries, international exchange of personnel can lead to a win-win situation, if two countries differ from each other in their “production” of human capital. For example, top colleges in the sending countries have become an important source of prospective students for graduate schools in the host countries; and the host countries in turn provides faculty members with overseas training to the sending countries. In the case of China, two of its top institutions, Tsinghua University and Beijing University, had overtaken the University of California, Berkeley in 2006, as the most fertile training ground for American doctoral programs (Mervis 2008). Meanwhile, the Chinese leading universities also recruited doctoral graduates from leading universities in the US. We find that 38.8% of returnees with foreign degrees in our sample graduated from the top 200 universities on the 2009 Jiaotong list, an educational environment that China is not yet close to being able to provide.

Moreover, skilled migration fosters knowledge diffusion, facilitates international collaboration, and pushes transnational investments, thereby benefiting both the source and the destination country. The results of Model 6-5 and 6-6 reveal that international collaboration in general, and collaboration with overseas Chinese in particular, were an important driver in improving the productivity of domestic scientists between 2002 and 2006 (see Table 6-15 and 6-16). China did experience a skilled emigration to the developed world, but it had also benefited from the knowledge flows facilitated by its skilled diaspora. As Table 7.2 suggests, China's intellectual loss due to the scientific brain drain would diminish, or even disappear, after we take international collaboration into account.

Second, negative connotations of brain drain are partly derived from "methodological nationalism", which refers to the naturalization of the global regime of nation states by the social sciences (Wimmer and Schiller 2003). "Seeing like a state[71]", we are used to viewing skilled emigration from a nationalistic perspective and often, if not always, ignore the interests of skilled migrants. Unlike flows of capital or commodities, migration flows change the definition of interest groups, and migrants can be categorized as nationals in the sending country, as residents of the receiving country, or as an independent group (Bhagwati 2011). "National welfare" depends on which country migrants are counted in.

Ironically, emigrants are often regarded as a "loss" to the source country, even if their departure increases the average welfare of its nationals. Clemens and Pritchett (2008) reveal that emigration actually raises the gross national product for most countries, if all nationals of a source country, including both emigrants and those left behind, are taken into consideration. Similarly, emigrant scientists in our sample exhibited significantly higher productivity than their domestic peers, and the total output of all Chinese scientists in the world was 73% larger than that of scientists in China in 2006. It is fair to say that the Chinese research community is much more developed from a Chinese perspective

[71] "Seeing like a state" is the title of a book on development by James Scott.

than from the perspective of China. For instance, the global scientific production would increase by 10% in the scenario of exodus, which results partly from the gain in the host countries (39.4%) and partly from higher productivity of domestic scientists driven by more international collaboration (7.7%).

Without realizing the great benefits brought by international migration, talent mercantilists often view outmigration of skilled workers as a problem to be controlled, rather than an opportunity to be embraced. Their mindset can easily lead to inconsistent policies toward internal and external migration. On the one hand, policymakers attempt to foster professional mobility within their jurisdictions; on the other hand, they are reluctant to facilitate outmigration of skilled workers to other countries. The European Union has frequently stressed the importance of brain circulation and implemented programs like ERASMUS and the Marie Curie scheme, which are supposed to facilitate mobility of research personnel between the member countries (Thorn and Holm-Nielsen 2006)[72]. Meanwhile, the EU is constantly concerned of the ongoing emigration of European scientists to the US and calls for measures to retain the "lost sons of Europe" (Morano-Foadi 2005).

Recent literature has challenged the zero-sum conceptualization of international competition for talent, and emphasized the complexity of skilled migration (Meyer 2001; Ionescu 2006). Some other scholars criticize policies based on talent mercantilism and advocate for relaxing migration restrictions, after they find that increasing South-North

[72] In addition, the EU has offered mobile researchers with social security and supplementary pensions for overcoming internal mobility barriers and built up the EURAXESS network (Ivancheva and Gourova 2011), which is seen as a major pillar for the creation of a single European academic market.

migration will bring enormous gains to the world (Pritchett 2006; Clemens 2009, 2010, 2011). Clemens and Pritchett (2008) argue that "departing one's country of birth is today one of the most important sources of poverty reduction for a large portion of the developing world." The simulation results in Section 7.2 similarly reveal that departing China is one of the most important sources of productivity increase for a considerable portion of Chinese scientists. The brains do not disappear. They just move and become brighter. Hence the new pro-migration advocates point out that "People develop, not places" (Clemens 2009). If skilled emigration not only fosters national development, but is national development, why should we worry about the issue of "brain drain"?

Although the pro-migration advocates have developed a powerful counterargument against talent mercantilism, their views go too far and ignore the justifiable interests of the source country in skilled migration. Places do not develop, but organizations do develop. To be more accurate, people in organizations develop. If some members of an organization move to join other organizations, their departure may have negative impacts on the organization's development, or on the remaining members' interests, particularly when the organization has a substantial stake in the leaving members. If a Chinese scientist migrates from China to the US, many Chinese may view his departure as a loss, because both places are not only parts of the world but also two nation states. When people say "China lost the scientist", "China" here refers to the political organization the "People's Republic of China", instead of the geographic region in East Asia.

There are losers and winners in the global competition for talent. As Section 7.1 shows, China's intellectual loss ranges from 2% to 40% of its total output in 2006, depending on different conditions (see Table 7.1 and 7.2). The country would only gain by a small margin (2.3%) in the last scenario with mixed conditions. By contrast, skilled emigrants bring large benefits to the host countries, as the total output of overseas Chinese represented 42.2% of all Chinese scientists at leading global universities. Here the key issue is not the outcome of the play, but whether it is fair play. Since the source country has invested in the human capital embedded in skilled emigrants by public education, it deserves the social return that matches the amount of investment. However, in reality, the host countries usually gain from the early education investment in the skilled emigrants. As the public funds in the source country become subsidies to the host country, DeVortze (1999) makes the accusation that: "Bill Gates and other extremely rich American entrepreneurs are being subsidized by these very poor countries' taxpayers."[73]

Bill Gates probably does not realize his benefits from such subsidies, and in Washington Post he once warned American leaders: "It's not in our national interest to educate them (foreign students) here but send them home when they've completed their studies" (Gates 2007). By the same logic, it is not in the national interest of other countries to educate their young students, and then to send them to the US when they have completed their studies, either. Despite the rhetoric of the "reverse brain drain" from the US, Gates' concern is largely unfounded according to our findings in Chapter 5. The US has retained the best of the best from China and will probably continue to do so, since the emigrant scientists from China were positively selected and the returnee scientists

[73] Such accusation can be found as early as the 1960's. After the British Royal Society released the report on the emigration of scientists from U.K., a reader commented: "the American state service, are compelled to live--and I am compelled to use the word--parasitically on the brains of other nations in order to supply their own needs (The Royal Society 1963)."

from the US were negatively selected. More importantly, both of the trends seem to become stronger over time. Hence the US does not need to worry about losing their research edge by the recent return flows. The real question regarding skilled migration is to address the interests of the source country as a key stakeholder in skilled emigration process.

Brain drain is also an issue of economic sustainability besides its ethical implications. Higher education expenditure in China was largely funded by the government utill the mid 1990s. Even in the marketization era, China has allocated billions of dollars to the national leading universities (Simon and Cao 2009, 117). One source estimates that the average government expenditure per student on tertiary education was around US$2000 in China in the late 1990's (Commander, Kangasniemi, and Winters. 2003, 11). At least in the short term, such fiscal loss might not be compensated by the positive feedbacks of brain drain. The Chinese government would be suspect of its huge higher education investment, if a large number of graduates at the top universities ended up in other countries and they did not make much of a contribution to Chinese society. The direct fiscal loss, as well as expected low social return, might cause underinvestment in the higher education sector in China, thereby sending fewer outstanding gradates to the host countries.

7.4 Policy recommendations

We have to ask "whose development" when we discuss policy issues related to skilled migration. The mercantilist perspective is restricted by methodological nationalism, while the new pro-migration perspective is biased by methodological individualism. Neither the national interests, nor the interests of emigrants, should be overemphasized from our perspective. Based on the findings of this dissertation, we attempt to give a set of policy recommendations, which may help the stakeholders balance their interests and share the enormous gain from skilled migration. We mainly focus on the policy implications for China, since this study was designed from a sending country perspective.

Here we first review China's policy related to overseas students in the past three decades. According to the official statistics, slightly over one million (1,067,000) Chinese students and scholars had pursued foreign study between 1978 and 2006, and only a quarter (25.8%) of them returned to China by the end of 2006 (Ministry of Education 2007). The phenomenal brain drain has often been criticized by the academia (e.g. Cao 2008) and the media (e.g. Pan 2010). As a reaction, the policy of the Chinese government evolved from a highly restrictive approach to a more liberal one.

China has a long tradition of exit restriction (Pina-Guerassimoff and Guerassimoff 2007), which turned into a status of near isolation during the Cultural Revolution. Tight regulations remained at the beginning of the reform era, though China's open-door policy started to allow its nationals to emigrate under certain conditions. Chinese college graduates had to go through complicated administrative procedures before obtaining their passports, if they wanted to attend foreign graduate programs. Not everyone affiliated with public research institutions were permitted to pursue overseas study. The government also set strict rules to punish state-sponsored overseas students who did not return (Xiang and Wei 2009, 3), in order to avoid problems associated with the brain drain.

Such restrictive measures had probably retained a considerable number of potential emigrant scientists in China, who helped expand the national talent pool. As Scenario II-2 shows, a 10% lower foreign education rate would lead to a gain of 4.3% for China in 2006, even after we adjusted the estimation according to the reduced degree of international collaboration. However, it is difficult for China, on the moral ground, to defend restrictions of its citizens' emigration. A scientific genius' departure might result in a "loss" for China, but it does not imply he did "harm" to the nation. The state may charge a reasonable exit tax from the emigrant as a compensation for the public expenditure on his education, but it has no right to restrict his freedom of movement in the name of "national interest".

At the beginning of 1990's, China gradually relaxed its exit control and tried to solve the brain drain problem by imposing a service period. The new rules required a university graduate to fulfill his social service in China for a certain number of years before his overseas study. The graduate was allowed to be exempted from the service period if he retuned a large part of his tuition fee to the government (Cao 2008). This compensation policy can be morally justified and did avoid direct fiscal losses to China, but it also discouraged Chinese students from advancing their academic career abroad, particularly for those from families of lower social and economic status. Poor college graduates were more likely to fulfill the service period due to liquidity constraints, and after working for several years in China, might have had to abandon their aspirations for overseas study.

The compensation policy probably did not benefit China much from a national perspective, either. Since younger scientists generally exhibit lower productivity than older ones, China might have gained less intellectual benefits by requiring young scholars to fulfill the service period than by allowing them to study abroad and luring them back after they had become mature researchers. The policy effect would become even worse, if China could not provide enough research jobs to those staying in the country. For instance, the half-employment scenario suggests that China's gain by retaining emigrant students would be substantially reduced by its limited R&D budget (see Table 7.1).

The Chinese government liberalized its policy regarding overseas education in the mid-1990s despite the brief period of restrictions after the Tiananmen incident in 1989. The new policy is often summarized by stressing its three components, namely "support overseas study, encourage returns, and guarantee freedom of movement" (Xiang 2003), which indicates a new orientation to the flexibility of skilled migration. For example, university graduates have not been required to return tuition fees or fulfill their service period since 2003. Combined with rapid higher education expansion, the new liberal policy helped push an unprecedented large wave of Chinese students to developed countries (Simon and Cao 2009, 223). China also initiated a series of policies to explore the growing overseas human resources. In retrospect, China's policy practice has been roughly consistent with the shifts in academic thinking on skilled migration from discouraging emigration in the 1980s to encouraging returns in the 1990s, and to utilizing skilled diaspora since the 2000s. Hence the policy recommendations given in this section do not seek to change the framework of the current policy; instead, they are composed of some specific suggestions based on the major findings in this dissertation.

Depending on the length and nature of mobility, skilled emigration has different effects on the source country. As Chapter 6.2 argues, China's recent scientific progress was largely driven by returnee scholars, who do not have formal foreign degrees. Because of family reasons or official requirements, this group of scientists was prone to return home after completion of their post-doc or visiting programs. Their brain circulation has contributed greatly to the scientific enterprise in China, witnessed by the big research gap between returnees and stayers. China's active policy was also important in shaping the outcome. For example, the Chinese government established the China Scholarship Council (CSC) under the Ministry of Education in the 1990s. Between 1996 and 2006, CSC sent 26 thousand students and scholars abroad and over 97% of them have returned to China (Yang 2006).

As a result, returnees have already dominated the academic leadership of Chinese higher education. Returnee scientists represented 78% of the presidents of universities under the direct control of the Ministry of Education, 63% of doctoral supervisors, and 72% of the directors of the national and provincial key labs in the early 2000's (Ministry of Education 2004). Two thirds of professors in top research organizations in Beijing and Shanghai were also reported to have two or more years of overseas experience (Jonkers 2010, Section 1.1). In order to internationalize its higher education sector, China should continue to send more university professors and doctoral students abroad for knowledge exchange and academic visits. Periodic program evaluations are also necessary to identify competent candidates and allocate funds more effectively.

By contrast, China only attracted a few emigrant scientists who graduated from top 200 universities in the world by 2006. China launched several talent programs targeting returnees from the late 1990's, such as the Chunhui Plan, the Yangtze River Scholar Plan, the Hundred Talents Programme, and the National Distinguished Young Scholars Program (Xiang 2003; Zweig 2006; Cao 2008). Chinese universities also competed with each other to attract overseas scientists, and provided them favorable conditions, such as suitable working platform, large research funds and sometimes a new research team, as well as free housing, high salary, and other benefits for their dependents. Despite some satisfactory cases, such as the One Hundred Talents Program at CAS (Liu and Zhi 2010), these programs have only achieved limited success in bringing back more productive scientists in terms of foreign degrees and working experience (Simon and Cao 2009, 240). Our data show that foreign degree holders only represented a small portion (23.1%) of all Chinese returnees at the leading universities in 2006. Although the observations are too limited to provide convincing evidences, at least we did not find that returnee students made extraordinary contribution to China. Since many returnee scientists who benefited from the programs are actually returnee scholars, China may consider narrowing its focus to outstanding foreign degree holders who have longer working experience in the fields in which China is lagging behind.

Favorable conditions for returnees may help lure overseas talent back home, but they may also induce unintended negative consequences in the domestic research system. An influx of returnee scientists has considerable impacts on the academic labor market in

China, as they compete with stayers for limited positions. China's policy has offered returnees with symbolic and political capital, as "holders of proper western degrees have more human capital, thus more social worth, and in turn deserve special economic and social privileges" (Xiang and Wei 2009). The social relations between returnees and stayers may generate segmentations in the scientific community in China, if the latter view the former with some suspicion and jealousy, particularly when returnees' contributions do not match their special benefits from the nation. For example, anecdotal evidences suggest that some returnees received higher salaries in China without fulfilling their research responsibilities (Xin 2006).

Returnees in our sample exhibited significantly higher productivity than stayers. The difference becomes moderate and statistically insignificant, however, after we controlled for professional status and administrative position. Returnees with higher research ability might be more likely to take important positions, if a merit-based evaluation system has been persisting in the Chinese academia. We can not rule out an alternative possibility, which points to a reversed causal link – returnees exhibited higher productivity because they were better able from their important positions to mobilize academic resources. The foundation of modern research universities depends on meritocratic values, and it is crucial to distribute research resources based on individual merit. At some point China may want to abolish the current programs favorable to returnees in order to treat all of its research personnel with fairness.

Possibly because Chinese policymakers were aware of the difficulties in attracting emigrant scientists, the official slogan referring to the overseas Chinese community shifted in the past decade from "returning and serving the country" to "serving the country", which encourages the scientific diaspora to engage in activities helpful for China, such as temporary service, while keeping their formal jobs abroad (Daugeliene and Marcinkeviciene 2009; Zweig, Fung, and Han 2008). As Meyer (2001) argues, the diaspora policy is different from the traditional human capital approach, since the former aims to tackle the large socio-professional networks, instead of the embedded knowledge of an individual scientist. The regression results in Section 6.3 confirm the effectiveness of the network approach and show a strong positive impact of international collaboration on individual productivity in China. More importantly, collaboration with overseas Chinese is particularly beneficial to domestic scientists.

Table 7.2 shows that China's intellectual loss is insignificant as international collaboration has compensated most for the lost output by emigrant scientists. China might have turned the brain drain into a brain gain after 2006, if domestic scientists conducted even more joint studies with foreign authors, including its expanding research diaspora. In this regard, China may want to consider establishing more academic connections with overseas scientists in the US, since they were less likely to collaborate with China than those in the ROW (see Table 6.14) and they also exhibited higher productivity. China may also want to facilitate communication between Chinese associate professors at foreign universities and the domestic scientific community, as they were least likely to collaborate with China.

Our findings also have policy implications for the host countries in general, and the United States in particular. The host countries have a big stake in the top universities in

China, as their graduates have become an important source for the talent pools in these countries. Hagopian et al. (2004) find that most of the African migrant physicians in the US graduated from a few medical schools in several Sub-Saharan countries. Our study also finds that the scientific brain drain from China mainly involved a few prestigious universities, as half or more of their alumni in academia obtained their highest degrees abroad and they tended to stay in their host countries. As China has been concentrating its limited resources to boost the teaching and research quality of national prestigious universities at the cost of less prestigious ones, the formers' high brain drain rate may cause considerable negative policy effects at least in the short term. The host countries, which benefit from the implicit "technological transfer," may offer financial aid to students at leading Chinese universities, particularly those with poor family background, as a compensation for China's loss of human capital. The aid will not only help more students overcome liquidity constraints to pursue further study, but also have a "brain gain" effect by raising the expected return of higher education.

In addition, the host countries can facilitate knowledge transfer to China by relaxing their visa policies. We asked the respondents' visa status in the survey and found that 63.3% of domestic scientists held a visiting scholar visa (e.g. the J-visa in the US) during their last long-term visit in their host country[74]. Foreign research centers of excellence can become more accessible to scientists from China and other developing countries, if the host countries can waive their visa requirements for short visits or simplify the application procedures. Some may worry that the recommended policies will assist China

[74] Here "long term" refers to a period of six months or longer.

to become a threatening competitor in the arena of science and technology. Here we only want to remind them that China has already assisted the research capacity building in the developed world by sending its students abroad in the first place, and S&T collaboration, including talent cooperation, is an important pillar for improving the bilateral relationships between China and the host countries.

Chapter 8 Conclusion

8.1 Summary of findings

This dissertation focuses on international migration of Chinese scientists between 1998 and 2006, as well as on their intellectual impacts. The sample includes 451 individual scientists at leading global universities in English academia. These leading scientists are carriers of cutting-edge knowledge and they make major contributions to the progress of science in China and in their host countries. Their movements between countries influence the construction of top research universities in China, which constitute flagships for the entire national academic system.

A scientific brain drain has mixed impacts on the research output in the source country. We highlight the major channels in a theoretical framework and have closely examined their effects in this dissertation. We first mapped the geographic distribution of Chinese scientists and identified their migration patterns. The number of scientists in China increased steadily, and the talent pool of overseas Chinese expanded even more rapidly. More Chinese students moved abroad for further study and stayed after graduation in the observation period. However, the return rate of foreign degree holders remained at a low level, though returnee students increased dramatically. Meanwhile, many domestic scientists without foreign degrees acquired overseas experience by short-term working or visiting programs, and three quarters of them had returned by 2006.

Hence the predominant mode of migration in this period was both an ongoing brain drain and an emerging brain circulation. Additionally, we also find considerable differences of migration patterns by cohort and field of study.

We then examined the selectivity of emigration and return flows in terms of educational background and other indicators. Chinese graduates from colleges in the upper two tiers were far more likely to receive foreign doctoral education than those from the third-tier schools. Moreover, foreign doctoral programs became more selective over time. The foreign academic markets were also selective, as doctoral graduates from universities with higher rankings had many more chances to work abroad than those from universities with lower rankings. By contrast, negative selection characterized the return migration of both foreign degree holders and their domestic counterparts, though the latter's selectivity was much weaker than the former's in terms of doctoral education background. Contrary to our expectation, the negative selectivity of return migration seemed to become stronger between 1998 and 2006 according to the descriptive analysis. However, the results from the regression analysis are too blurred to be conclusive.

Moguerou (2006) argues that the analysis of stay rates of foreign students in the US is not complete without taking the "quality" of returnee scientists into account. This dissertation has partially filled this literature gap. The US remains the primary destination country for excellent Chinese students, and the rhetoric of a "reversed brain drain" is largely unfounded according to our findings. However, the impacts of skilled emigration on the source country are still unclear. Can a brain drain be economically sustainable and ethically justifiable? This is the truly important problem regarding the international migration process. Hence we in turn focused on the contributions brought by returnee scientists and the research diaspora to China, thereby responding to the research agenda of brain circulation (Meyer 2001; Ackers 2005a).

We find that the differences in research productivity between Chinese scientists in China and those outside China were reduced substantially between 1998 and 2006 in terms of average productivity or highest performance, although the tendency and selectivity of emigration became stronger over time. As a result, China had dominated the research output of Chinese scientists at leading global universities in 2006. The major driving force behind the narrowing trend was the rising productivity of domestic scientists in general, and the rapidly growing output of returnee scholars in particular.

The overall return rate of Chinese scientists jumped to 48.6% in 2006, which indicates that half of those with overseas experience for more than two years had returned to China by 2006. The absolute majority of returnees were composed of returnee scholars, whose participation in China's scientific production became more important over time. The average output of returnees grew so rapidly that it already surpassed that of emigrants in the ROW (the rest of the world) in 2006, and greatly narrowed its gap with that of emigrants in the US. By contrast, we find no significant contribution of returnee students to China's scientific development in the period.

The negative binomial regression results show that returnees were much more productive than stayers. However, the former's advantage becomes insignificant after the control for professional status and administrative position, which leaves a puzzle unsolved in this dissertation. Our current sample is inadequate to disaggregate the effects of overseas experience and resource mobilization on the "return premium." Future research can collect longitudinal data of publication records and trace the causal links between foreign knowledge, productivity gain, and promotion.

In addition to the benefits brought back by returnees, the professional connections between the scientific diaspora and scientists in China were found to alleviate the losses associated with the brain drain. Emigrant students made up the lion's share of overseas scientists, as most emigrants obtained foreign doctorates before they were formally employed abroad. Their advanced foreign education raised their research productivity, which in turn helped transfer cutting-edge knowledge to their domestic peers through international collaboration. On the one hand, the proportion of emigrants who collaborated with China had more than doubled between 1998 and 2006 in terms of coauthored papers. On the other hand, collaboration with overseas Chinese represented a large part of all international collaboration by domestic scientists in 2006. We also find that senior scientists on both sides were more likely to collaborate with each other than junior scientists.

The regression analysis on productivity demonstrates that the productivity level of scientists in China was determined by international collaboration in general, and collaboration with overseas Chinese in particular. Domestic scientists who had collaborated only with overseas Chinese were almost twice as productive as those without such collaboration, even after we controlled for the factor of international collaboration. In addition, collaboration with emigrant scientists had more influence on individual highest performance than on research output, while returnees' contribution to the average output in China was more significant than their achievements in the high end.

In order to evaluate the overall impact of a scientific brain drain, we have to estimate not only the positive feedbacks but also the potential losses. Next we attempted to explore whether China would have higher research output if the scientific brain drain did not occur. We answered this counterfactual question by simulating scenarios where emigrant students stayed in China for study and work. The simulation outcomes based on previous empirical findings demonstrated that the intellectual loss to China looks striking under the ideal conditions, but it is reduced substantially in more realistic scenarios with a limited budget, fewer job opportunities, and less international collaboration. As the last scenario with mixed conditions shows, the scientific brain drain might have little impact on China's total research output in 2006, because the positive feedbacks would counterbalance the negative impacts.

Finally, we have explored the intellectual consequences in scenarios with different return rates and foreign education rates. According to the estimated outcomes, each migration trend has opposite effects on China and the world. Chinese scientists would make greater contribution to the world, if more of them moved abroad and exhibited higher productivity than their real performance in China. However, China's research output would be lower than the current level, since additional returnees and international collaboration would not be enough to compensate for its lost manpower.

The ethical question of brain drain emerges here with strong policy implications. Our position is not consistent with talent mercantilism, which is restricted by methodological nationalism; nor do we fully agree with the pro-migration advocates, whose views are biased by methodological individualism. On the one hand, we insist that brain drain is a serious problem and the interests of the source country should be incorporated in the policy thinking. On the other hand, we oppose restrictive measures as a solution to brain drain, either because they can not be justified by limited obligation of emigrants to the home country, or because they are counterproductive in improving the global welfare by skilled migration. Instead, we recommend some specific policies to both China and the host countries, so that they can balance their interests and share the enormous gain in a win-win situation. These recommended policies include targeting more qualified returnees, allocating resources based on merit, further enhancing international collaboration, and providing financial aid to Chinese universities with high emigration rates.

There is a Chinese saying that says "moving makes a tree die, but a man thrive". The findings of this dissertation shed light on the important role of migration in promoting scientific progress, and contribute to the rich debate on the issue of brain drain. We have examined the impacts of skilled flows empirically and also conducted counterfactual analysis explicitly in the setting of the migration of Chinese scientists. In particular, the dissertation fills a gap in the literature on research collaboration by focusing on the relationship between joint research with the diaspora and productivity growth in the home country.

8.2 Limitation and future research

This dissertation has some limitations with respect to the sample, which may affect the accuracy of the findings. The target population did not cover Chinese scientists in Japan and other non-English speaking countries, thereby underestimating the outflow of the scientific brain drain. The sampling frame narrowed its focus on leading Chinese universities, and excluded scientists working for public research organizations, such as the Chinese Academies of Sciences (CAS). This omission might lead to an underestimation of the contribution of returnees, if public organizations in China proportionally attracted more foreign degree holders than universities.

This study also suffered from a low response rate and a small sample size. Although we adopted several important measures, such as reminder letters, personalized invitation, and organizational endorsement, the overall response rate was estimated to be only 22.8%. About one third of faculty members in China, particularly those who worked at universities with lower rank, were not accessible due to the unavailability of email. The sample size of returnees with a foreign degree is quite small, and the findings related to this group of scientists are not conclusive. The selections bias in terms of location, discipline, and university ranking had been reduced to some extent thanks to the weighting method[75]. Future research may attempt to generate a more comprehensive sample with a higher response rate.

[75] We could compare the sample and the sampling frame only by the three variables. Other information of non-respondents was not available. However, we divided respondents into two groups and compared their demographic profiles – those who filled the questionnaire before receiving a reminder letter and those who did so after receiving the letter. If we assume the profile of non-respondents resembles that of the latter group, females, those in China, and those working at less prestigious universities were found to be slightly

Although we collected biographical and bibliometric records in the three observation years, the cross-sectional nature of the data inhibits our ability to conduct more complicated longitudinal analysis. For example, future studies may observe productivity change of migrant scientists in different locations by collecting their continuous publication records, which may help disaggregate the effect of self-selection and that of academic environment. In order to detect the influences of migration experience on individual research performance, event history analysis is also applicable to pertinent longitudinal data.

The measurements used in this study may also lead to inaccurate findings. We adopted a single indicator to measure research output by combining quantitative and qualitative dimensions. Despite its advantage of simplicity, the indicator does not take disciplinary difference into account, and it is not adjusted according to annual "inflation" of citation rates. For the purpose of consistency, future research may use more sophisticated bibliometric methods to normalize research output in different disciplines or periods. In addition, the measurements of international collaboration in this study were too crude to show the degree of collaboration among those who had coauthored papers with foreign scholars. In the future, students of migration may not only generate quantitatively more accurate indicators in this regard, but also check the backgrounds of one's collaborators.

Finally, this study did not examine influences of knowledge flows, though this factor has been incorporated into the theoretical framework. Future discussion should

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less represented in the sample. We did not find significant selection bias in terms of productivity or international collaboration by this comparison.

take its effect into account in order to evaluate the overall impact of a brain drain. The nature of knowledge flows, including non-rivalry and non-excludability, offers enormous possibility of turning a brain drain into a gain. Future studies may explore the roles of emigration and return migration in facilitating international knowledge diffusion. As the quotation of Louis Pasteur suggests at the beginning of the first chapter, the boundaries of the scientific community and national borders are not always consistent; but he also put it in this way:

"*Knowledge belongs to humanity, and thus science knows no country and is the torch that illuminates the world.*"

Appendix I Indicators and Weights for Academic Ranking of World Universities (ARWU)

Criteria	***Indicator***	***Code***	***Weight***
Quality of Education	Alumni of an institution winning Nobel Prizes and Fields Medals	Alumni	10%
Quality of Faculty	Staff of an institution winning Nobel Prizes and Fields Medals	Award	20%
	Highly cited researchers in 21 broad subject categories	HiCi	20%
Research Output	Papers published in Nature and Science*	N&S	20%
	Papers indexed in Science Citation Index-expanded and Social Science Citation Index	PUB	20%
Per Capita Performance	Per Capita Performance Per capita academic performance of an institution	PCP	10%
Total			100%

Source: http://www.arwu.org/ARWUMethodology2009.jsp

Indicator	***Definition***
Alumni	The total number of the alumni of an institution winning Nobel Prizes and Fields Medals. Alumni are defined as those who obtain bachelor, Master's or doctoral degrees from the institution. Different weights are set according to the periods of obtaining degrees. The weight is 100% for alumni obtaining degrees in after 1991, 90% for alumni obtaining degrees in 1981-1990, 80% for alumni obtaining degrees in 1971-1980, and so on, and finally 10% for alumni obtaining degrees in 1901-1910. If a person obtains more than one degrees from an institution, the institution is considered once only.
Award	The total number of the staff of an institution winning Nobel Prizes in Physics, Chemistry, Medicine and Economics and Fields Medal in Mathematics. Staff is defined as those who work at an institution at the time of winning the prize. Different weights are set according to the periods of winning the prizes. The weight is 100% for winners in after 2001, 90% for winners in 1991-2000, 80% for winners in 1981-1990, 70% for winners in 1971-1980, and so on, and finally 10% for winners in 1911-1920. If a winner is affiliated with more than one institution, each institution is assigned the reciprocal of the number of institutions. For Nobel prizes, if a prize is shared by more than one person, weights are set for winners according to their proportion of the prize.
HiCi	The number of highly cited researchers in 21 subject categories. These individuals are the most highly cited within each category. The definition of categories and detailed procedures can be found at the website of Thomson ISI.
N&S	The number of papers published in Nature and Science between 2004 and 2008. To distinguish the order of author affiliation, a weight of 100% is assigned for corresponding author affiliation, 50% for first author affiliation (second author

	affiliation if the first author affiliation is the same as corresponding author affiliation), 25% for the next author affiliation, and 10% for other author affiliations. Only publications of 'Article' and 'Proceedings Paper' types are considered.
PUB	Total number of papers indexed in Science Citation Index-Expanded and Social Science Citation Index in 2008. Only publications of 'Article' and 'Proceedings Paper' types are considered. When calculating the total number of papers of an institution, a special weight of two was introduced for papers indexed in Social Science Citation Index.
PCP	The weighted scores of the above five indicators divided by the number of full-time equivalent academic staff. If the number of academic staff for institutions of a country cannot be obtained, the weighted scores of the above five indicators is used. For ARWU 2009, the numbers of full-time equivalent academic staff are obtained for institutions in USA, UK, France, Canada, Japan, Italy, China, Australia, Netherlands, Sweden, Switzerland, Belgium, South Korea, Czech, Slovenia, New Zealand etc.

Source: http://www.arwu.org/ARWUMethodology2009.jsp

Appendix II Interview Schedule

Please read the instructions carefully in this questionnaire. Thanks.

*Q1. Please copy your ID number and paste it in the blank space (you can find it at the end of the invitation letter):

Q2. Please type your English name on journal publications, if you have one:
Last name (surname)_______ First name (given name)_______

Q2*. Please type your Chinese name with characters if it is not difficult to do so：

____

Q3. If you can only choose one option, which sub-field do you think you belong to? (Fields in mathematics, physics, chemistry, and biology are listed sequentially)

Algebra and Number Theory	Organic chemistry
Geometry and Topology	Inorganic chemistry
Differential, Integral, and Difference Equations	Analytical chemistry
Probability theory and statistics	Physical chemistry
Computational Mathematics	Biochemistry
Other fields in mathematics	Other fields in chemistry
Condensed matter and material science	Genetics
High energy, particles and fields	Molecular biology
Nuclear physics	Cell biology
Optics	Developmental Biology
Applied physics	Ecology
Other fields in physics	Other fields in biology

Q4. Besides your major field, please choose your minor fields if you have any (you can make multiple choices; fields in mathematics, physics, chemistry, and biology are listed sequentially): (Options are the same as Q4)

Q5. Are you:
□ Male □ Female

Q6. In what year were you born? (You can find the year from the drop-down menu.)
(Respondents can choose a year between 1945 and 1990)

Q7. Which province were you born in? (Please choose an answer from the drop-down menu, which lists 31 Chinese provinces alphabetically, in addition to a choice "outside mainland China") (Respondents can choose a province from the options)

Q8. When you were a middle school student, what was your Hukou status?
□ Urban □ Rural □ Not applicable

Q9. In what year did you obtain a bachelor degree? (You can find the year from the drop-down menu. Please specify the year if you obtained a bachelor degree before 1977)
(Respondents can choose a year between 1977 and 2005)

Q10. From which university did you get a bachelor degree? (You may choose one from the drop-down menu, which lists 34 Chinese universities alphabetically)

Beijing Institute of Tech
Beijing Normal Univ
Beijing Univ of Aero and Astro
Central South Univ of Tech
China Agr Univ
Chongqing Univ
Dalian Univ Tech
East China Univ of Sci and Tech
Fudan Univ
Harbin Inst Tech
Huazhong Univ Sci & Tech
Hunan Univ
Jilin Univ
Lanzhou Univ
Nanjing Agr Univ
Nanjing Univ
Nanjing Univ of Aero and Astro
Nankai Univ
Northwestern Polytechnical University
Peking Univ
Shandong Univ
Shanghai Jiao Tong Univ
Sichuan Univ
South China Univ of Tech
Southeast Univ
Tianjin Univ
Tongji Univ
Tsinghua Univ
Univ Sci & Tech China
Wuhan Univ
Xiamen Univ
Xi'an Jiaotong Univ
Zhejiang Univ
Zhongshan Univ

Q11. In what year did you obtain your highest degree? (You can find the year from the drop-down menu.Please specify the year if you obtained your highest degree before 1977.)

Q12. Was your highest degree at master or doctoral level?
□ At master level □ At doctoral level

Q13. From which university did you obtain your highest degree? (You may choose one from the drop-down menu, which alphabetically lists 34 universities in mainland China and Chinese Academy of Sciences, in addition to 79 leading universities in several English-speaking countries. Please specify the university in either English or Chinese if you can't find it from the drop-down menu.)

Australian Natl Univ
Brunel Univ
Chinese Univ Hong Kong
City Univ Hong Kong
Univ Massachusetts Med Sch
Univ Michigan - Ann Arbor
Univ Missouri - Columbia
Univ Newcastle-upon-Tyne

City Univ New York - City Coll
Columbia Univ
Dartmouth Coll
Drexel Univ
Flinders Univ South Australia
Florida State Univ
Hong Kong Polytechnic Univ
Hong Kong Univ Sci & Tech
Imperial Coll London
Indiana Univ - Purdue Univ - Indianapolis
La Trobe Univ
London Sch Hygiene & Tropical Med
Louisiana State Univ - Baton Rouge
Macquarie Univ
Michigan State Univ
Montana State Univ - Bozeman
Mt Sinai Sch Med
Nanyang Tech Univ
Natl Univ Singapore
New York Univ
North Carolina State Univ - Raleigh
Open Univ
Purdue Univ - West Lafayette
Queen's Univ
Rice Univ
San Diego State Univ
State Univ New York - Buffalo
Syracuse Univ
Thomas Jefferson Univ
Univ Alabama - Birmingham
Univ Alberta
Univ Arizona
Univ Arkansas - Fayetteville
Univ Bath
Univ Bristol
Univ British Columbia
Univ California - Berkeley
Univ California - Davis
Univ California - Irvine
Univ California - Riverside
Univ California - San Diego
Univ California - Santa Barbara
Univ Cambridge
Univ Connecticut - Storrs
Univ Connecticut Health Center
Univ North Carolina - Chapel Hill
Univ Nottingham
Univ Oregon
Univ Ottawa
Univ Quebec
Univ Queensland
Univ St Andrews
Univ Texas Health Sci Center - Houston
Univ Texas Health Sci Center - San Antonio
Univ Virginia
Univ Waterloo
Univ Wisconsin - Madison
Univ Wollongong
Victoria Univ Wellington
Virginia Tech
Washington Univ - St. Louis
Wayne State Univ
Yale Univ
Beijing Institute of Tech
Beijing Normal Univ
Beijing Univ of Aero & Astro
Central South Univ of Tech
China Agr Univ
Chongqing Univ
Dalian Univ Tech
East China Univ of Sci and Tech
Fudan Univ
Harbin Inst Tech
Huazhong Univ Sci & Tech
Hunan Univ
Jilin Univ
Lanzhou Univ
Nanjing Agr Univ
Nanjing Univ
Nanjing Univ of Aero and Astro
Nankai Univ
Northwestern Polytech University
Peking Univ
Shandong Univ
Shanghai Jiao Tong Univ
Sichuan Univ
South China Univ of Tech
Southeast Univ
Tianjin Univ
Tongji Univ

Univ East Anglia
Univ Florida
Univ Guelph
Univ Hertfordshire
Univ Hong Kong
Univ Kansas - Lawrence
Univ Leeds
Univ Maryland - Baltimore
Tsinghua Univ
Univ Sci & Tech China
Wuhan Univ
Xiamen Univ
Xi'an Jiaotong Univ
Zhejiang Univ
Zhongshan Univ

Q14. What was your professional status (or equivalent status) at your affiliation in the academic year 2008-09?

□ Lecturer/Assistant professor/researcher
□ Associate professor/researcher
□ Full professor/researcher
□ Other (please specify)

Q15. Did you take any administrative position in the academic year 2008-09? If yes, please choose a position.
□ Not any
□ Dean
□ Assistant dean
□ Director of any research/education center
□ Chair of any committee
□ Other (please specify)

We are mainly interested in your career trajectory in three academic years, 1997-98, 2001-02 and 2005-06. Please answer the following questions based on your CV.

Please notice that your "affiliation" has a formal employment relationship with you. It is NOT any academic institution you visited temporarily.

If you obtained the highest degree AFTER June 1998 AND had no previous working experience, please skip to the next page.)

Q16. What was your professional status (or equivalent status) at the academic institution you affiliated with in the academic year 1997-98?
□ Doctoral student/research assistant
□ Post-doc
□ Lecturer
□ Assistant professor/researcher
□ Associate professor/researcher
□ Full professor/researcher
□ Other (please specify)

Q17. Which academic institution were you affiliated with in the academic year 1997-98? (You may choose one from the drop-down menu, which alphabetically lists 34 universities in mainland

China and Chinese Academy of Sciences, in addition to 79 leading universities in several English-speaking countries. If it was the same one as your current affiliation, please choose the first choice.)

Please specify the academic institution if you can't find it from the drop-down menu (in either English or Chinese):

(Options are the same as Q13)

Q18. Did you take any administrative position in the academic year 1997-98?
□ Not any
□ Dean
□ Assistant dean
□ Director of any research/education center
□ Chair of any committee
□ Other (please specify)

Q19. Did you visit another academic institution AND stay there in the majority (over six months) of the academic year 1997-98? (If you answer "no", please skip to the next page by clicking "Next" at the end of this page.)
□ Yes □ No

Q20. Which academic institution did you visit in the academic year 1997-98? (You may choose one from the drop-down menu, which alphabetically lists 34 universities in mainland China and Chinese Academy of Sciences, in addition to 79 leading universities in several English-speaking countries.)
Please specify the academic institution if you can't find it from the drop-down menu:

(Options are the same as Q13)

If you obtained the highest degree AFTER June 2002 AND had no previous working experience, please skip to the next page.)

Q21-25 repeat Q16-20, respectively. The only difference is that they elicit information about the 2001-02 academic year. So do Q26-30 for 2005-06 academic year.

Q31. How much time in total had you stayed OVERSEAS for study or work between July 2006 and June 2009? (Please notice that "overseas" includes Hong Kong, Taiwan, and Macao.)
□ Stayed in China during the entire period
□ Less than 3 months
□ Between 3 and 6 months
□ Between 6 months and 1 years
□ Between 1 and 2 years
□ Between 2 and 3 years

Q32. If you obtained the highest degree BEFORE July 2006, how many years in total had you stayed overseas for study and work by then (July 2006)? (Please choose from the drop-down menu. Please choose "0" if you had no overseas experience.)

(Respondents can choose between 0 and 30 years)

Q33. If you obtained your highest degree BEFORE July 2002, please pick a phrase which best describes your mobility history between July 1998 and June 2002 (please notice that "China" and "Chinese" only refer to mainland China; "overseas" includes Hong Kong, Taiwan, and Macao):
□ Not applicable (graduation after July 2002)
□ Primarily staying in China with cumulative overseas academic experience less than 9 months
□ Job transfer/academic visits from a Chinese institution to an overseas one; and stayed overseas between 9 months and 2 years cumulatively
□ Job transfer/academic visits from a Chinese institution to an overseas one, and stayed overseas for over 2 years cumulatively
□ Job transfer/academic visits from an overseas institution to a Chinese one; and stayed in China between 9 months and 2 years cumulatively
□ Job transfer/academic visits from an overseas institution to a Chinese one, and stayed in China for over 2 years cumulatively
□ Primarily staying overseas with cumulative academic experience in China less than 9 months

Q34. If you obtained your highest degree BEFORE July 2006, please pick a phrase which best describes your mobility history between July 2002 and June 2006:

(Options are the same as Q33)

Q35. If you obtained your highest degree BEFORE July 2006, please pick a phrase which best describes your mobility history between July 1998 and June 2006:
□ Not applicable (graduation after July 2006)
□ Primarily staying in China with cumulative overseas academic experiences less than 2 years
□ Primarily staying in China with cumulative overseas academic experience over 2 years
□ Previously stayed overseas and returned to China for full-time employment before July 2002
□ Previously stayed overseas and returned to China for full-time employment after July 2002
□ Primarily staying overseas with cumulative academic experience in China less than 1 year
□ Primarily staying overseas with cumulative academic experience in China over 1 year

Q36-1. What was your visa status in the host country on Jan 1, 2009?
□ Not applicable (still in China)
□ Student visa（e.g. F-1 in the U.S.)
□ Visiting scholar visa（e.g. J-1 in the U.S.)
□ Temporary working visa（e.g. H-1B in the U.S.)
□ Business visa（e.g. B-1 in the U.S.)
□ Employment-based immigration visa（e.g. EB-1 green card)
□ Family-based immigration visa (e.g. IR-1 green card)
□ Citizenship of the host country
□ Other (please specify)

Q36-2. If you have ever stayed overseas relatively long-term (over six months) for academic

purposes, what was your visa status during your last long-term visit in the host country?
□ Not applicable (have never stayed overseas more than six months)
□ Student visa （e.g. F-1 in the U.S.)
□ Visiting scholar visa （e.g. J-1 in the U.S.)
□ Temporary working visa （e.g. H-1B in the U.S.)
□ Business visa （e.g. B-1 in the U.S.)
□ Employment-based immigration visa （e.g. EB-1 green card)
□ Family-based immigration visa (e.g. IR-1 green card)
□ Citizenship of the host country
□ Other (please specify)

Q37. If you have an overseas degree or work experience, have you ever participated in any program that favored returnees in terms of living or working conditions? (You can make multiple choices).
□ Not applicable (have no or little overseas experience)
□ Program at national level
□ Program at provincial/municipal level
□ Program at working unit level
□ Never participated in one
□ Other program (please specify):

I appreciate the time you spent for this interview. It is very helpful for my research and I'll be excited to share the results with you!

Appendix III Detailed Coding Table of College Degree

Tier	*Frequency*	*University*	
First	2	Peking Univ	Tsinghua Univ
Second	7	Fudan Univ	Nanjing Univ
		Shanghai Jiao Tong Univ	Univ Sci & Tech China
		Xi'an Jiaotong Univ	Zhongshan Univ
		Zhejiang Univ	
Third	13	Beijing Institute of Tech	Beijing Normal Univ
		Beijing Univ of Aero & Astro	Harbin Inst Tech
		Huazhong Univ Sci & Tech	Jilin Univ
		Lanzhou Univ	Nankai Univ
		Shandong Univ	Sichuan Univ
		Tongji Univ	Wuhan Univ
		Xiamen Univ	
Fourth	12	Central South Univ of Tech	China Agr Univ
		Chongqing Univ	Dalian Univ Tech
		East China Univ of Sci and Tech	Hunan Univ
		Nanjing Agr Univ	Nanjing Univ of Aero and Astro
		Northwestern Polytech University	South China Univ of Tech
		Southeast Univ	Tianjin Univ
Total			34

Note: Universities not in the list are categorized into the fourth class.

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List of References

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