Elite Scientists and the Global Brain Drain

Showkat Ali, Giles Carden, Benjamin Culling, Rosalind Hunter, Andrew J Oswald, Nicola Owen, Hilda Ralsmark, Natalie Snodgrass

No 825

WARWICK ECONOMIC RESEARCH PAPERS

DEPARTMENT OF ECONOMICS

THE UNIVERSITY OF WARWICK

Elite Scientists and the Global Brain Drain

A paper by the University of Warwick, U.K.

Authors
Showkat Ali
Giles Carden
Benjamin Culling
Rosalind Hunter
Andrew J Oswald
Nicola Owen
Hilda Ralsmark
Natalie Snodgrass

University of Warwick
Coventry
CV4 7AL
United Kingdom

September 2007

To be presented at the World Universities Conference in Shanghai, October 2007

Acknowledgements: For helpful discussions, we thank David Blanchflower, Jonathan Cave, Amanda Goodall and Simon Hands.

Elite Scientists and the Global Brain Drain

Summary

There are signs – one is world university league tables – that people increasingly think globally when choosing the university in which they wish to work and study. This paper is an exploration of data on the international brain drain. We study highly-cited physicists, highly-cited bio-scientists, and assistant professors of economics. First, we demonstrate that talented researchers are being systematically funnelled into a small number of countries. Among young economists in the top American universities, for example, 75% did their undergraduate degree outside the United States. Second, the extent of the elite brain drain is considerable. Among the world's top physicists, nearly half no longer work in the country in which they were born. Third, the USA and Switzerland are per capita the largest net-importers of elite scientists. Fourth, we estimate the migration 'funnelling coefficient' at approximately 0.2 (meaning that 20% of top researchers tend to leave their country at each professional stage). Fifth, and against our prior expectations, the productivity of top scientists, as measured by the Hirsch h-index, is similar between the elite movers and stayers. Thus it is apparently not true that it is disproportionately the very best people who emigrate. Sixth, there is extreme clustering of ISI Highly Cited Researchers into particular fields in different universities. Seventh, we debate the questions: are the brain drain and this kind of funnelling good or bad for the world, and how should universities and governments respond?

Elite Scientists and the Global Brain Drain

1. Introduction

It is evening. There is snow on the ground. Inside, a grey-haired Englishman in a white bow tie steps forward, and Anthony Leggett lifts something small into the air. Photographers strain forward and the gold of the Nobel Prize in Physics flashes back from his hand. A second Englishman, Peter Mansfield, emerges from the wings. This time it is the Nobel Prize in Physiology and Medicine that is held toward the cameras. A third Briton joins them. Amid Swedish and foreign reporters, Clive Granger raises aloft the Nobel Prize in Economics. The date is December 10, 2003. Next morning, the readers of The New York Times learn little of the trio's common birthplace. Instead they discover, correctly, that Americans again scooped the bulk of the Nobel awards in Stockholm, but that an elderly medical scientist from England received one. By then, Professor Anthony Leggett, born a Londoner, is en route back to his laboratory in Illinois. Professor Clive Granger, originally from Swansea, is sitting westbound on an aeroplane and writing the next of his University of California lectures.

This is a study of the brain drain and why it may matter. We examine the migration decisions made by some of the world's most creative scientists. Our paper lays out data on the mobility of three kinds of university researchers. Its focus is senior physicists, senior bio-scientists, and assistant professors in the top American economics departments. In this way, we hope the paper provides a flavour of science and social science, and of old and young.

Our data on senior physicists and bio-scientists are drawn from the ISI Web of Science database known as www.isihighlycited.com. This lists the world's most-cited people across a range of 21 subject fields. The database seems particularly valuable, even though it is still relatively un-exploited, as a source of information on scientists, both because of the talented nature of the group (many of the men and women in our data set are likely to go on to win Nobel Prizes) and because it is possible to link bibliometrically to most of these scientists' published articles. Information on factors such as the citations h-index, as suggested by Hirsch (2005), can thereby be studied directly. Although it has recently become possible to draw upon Google Scholar to construct h-indexes, in this paper we rely on data from ISI.

The paper is interested in a number of questions:

- Among elite scientists, how strong is the world's brain drain?
- Is it disproportionately the very best researchers who migrate?
- Why are certain countries successful at attracting top scientists? Should governments try particularly to retain young stars, and if so how might they do so?
- Is the brain drain beneficial for the world as a whole or merely good for the acquiring country (often, in our data, the United States)? Can we quantify the nature of the loss to a donor nation?
- How can we measure the average quality of movers compared to stayers?
- How much 'clustering' of elite scientists is there? In other words, do particular universities attract star researchers if they already have brilliant people in those particular fields?
- Might clustering create too much conformity of thinking?
- If increased publicity given to world rankings of university-quality encourages more international mobility in the future, what are the policy implications of the brain drain, if any, for the welfare of the world as a whole?
- Should individual governments have policies to slow the elite brain drain?
- How ought a university to react strategically to the existence of these kinds of brain drain pressures?

We believe these questions are important. Our paper provides evidence relevant to some, and speculates on others, although we shall not be able definitively to answer all of them.

Part of our aim is to measure the productivity of researchers. There are two main ways to do this. One is to count the number of papers produced by a scholar. The other is to count a scholar's citations (that is, the number of times that he or she is referenced in others researchers' bibliographies). We adopt principally the latter. Particular emphasis is given here to a scholar's h-index. An h-index is a summary statistic that is becoming widely used in bibliometric inquiries. A scholar who has published Z papers each of which has been cited at least Z times is said to have an h-value of Z. It tells us in a quick way how highly cited a person is, and is calculated by rank-ordering a scholar's journal papers by how many times each paper has been cited, and then solving for the highest integer defined by the equality: *the number of cites = the number of that paper in the rank ordering*. For example, consider someone who had published eight journal articles that have been cited respectively 0 times, 0 times, 0 times, 3 times, 4 times, 5 times, 6 times and 7 times. This scholar's h-index would be 4. Such a person has published 4 articles cited at least 4 times.

Nevertheless, other approaches are possible. Hence at one or two points in the paper we use, as an alternative, the total number of lifetime citations to an individual's work.

One potential weakness of our analysis ought be acknowledged from the outset. Because we shall be using data from ISI, this paper will concentrate on scientific work published in English-language research articles. As in so much bibliometric analysis, this leads to an undercounting of research results written only in other languages. At the time of writing, it is not possible to correct in a systematic way for this bias, although in the long run it may be that exactly comparable citations indexes in other languages will be developed.

2. The Brain Drain: Background

Higher education is big business. More than 2 million European Union students graduate each year, and approximately 2 million also do so in the United States. Despite this, the EU employs many fewer researchers per 1,000 workers (5.4%) in the labour force when compared to the US (8.7%): see the data in Woods (2003). The measured trans-Atlantic drain is numerically fairly small and has been estimated to be 0.5%-1% (Saint-Paul, 2004). Nevertheless, the migrants are top performers within their fields. When only considering the United States labour force with doctoral degrees in the Science and Engineering field, 29% of those conducting R&D are foreign-born (Johnson and Regets, 1998).

In 2001, the European Council of Ministers adopted ‘The Barcelona Objective’, stating that all EU members should spend a minimum of 3% of GDP on research by 2010 (EC, 2002). At that point, the EU was estimated to spend 1.9%, compared to the US’s value of 2.8%. This strategy was meant to create 400,000 new jobs for European scientists every year (Woods, 2003). Yet, by 2003, only a few countries had met the criteria. The gap between EU and US research spending continues to widen.

The concept of the ‘brain drain’ – the intellectual seepage from a country caused by the emigration of highly-educated personnel – is now a fairly old one. It appears to have gained currency in the 1960s following the prominence given to the phenomenon by a report published by the Royal Society (Royal Society, 1963). That report tried to measure the exodus of British scientists to the United States. Early research on the subject was principally concerned with the emigration of academics and professionals from developing to developed countries, and the possible negative impacts of this migration on the social and economic development of the countries of origin (Bhagwati and Hamada, 1974; Hamada, 1977; McCullock and Yellen, 1977).

Since then, the focus of study has shifted. It has come to take into account a wider understanding of the international mobility of elites, and the conventional wisdom that the brain drain is always negative for the development of source countries has now been displaced in favour of the related concept that it is necessary to balance also the benefits of ‘brain gain’ and ‘brain circulation’. This new perspective is demonstrated through more recent literature in the field, which posits that – at least in the case of larger developing countries with an intermediate level of income – the emigration of intellectual capital, and the prospect of migration, has the potential to encourage human capital formation through inducing greater educational aspirations and additional investment in education, and additionally that past skilled emigration significantly increases a country’s chances of attracting foreign direct investment in the subsequent period through skilled migrants’ active participation in facilitating such transfers between their host and home countries (Commander, Kangiasniemi and

Winters, 2003; Kugler and Rapoport, 2007; Meyer, 2001; Mountford, 1997; Beine, Docquier and Rapoport 2001, 2007). Beyond diaspora externalities and the effects of the raising of expected returns to education, a number of authors have also discussed the relatively short-term nature of movements in pursuit of career development, the higher incidence of migration among potential rather than established elites, and the increasing characterisation of the movements of the highly-educated as circulation and mobility rather than migration (e.g. Bekhradnia and Sastry, 2005; Gaillard and Gaillard, 1997; Laudel, 2005; Meyer, 2001; UUK, 2007).

In the early literature, quantitative measurements of the magnitude of the brain drain were uncommon. More recently, empirical studies have begun to emerge. Carrington and Detragiache's (1998, 1999) work was pioneering. It provided skilled migration rates for 61 developing countries in 1990 by using US census and OECD migration statistics. Notwithstanding the limitations of the data and methodology, as detailed by Docquier and Rapoport (2007), the report of Carrington and Detragiache demonstrated a substantial brain drain to the United States, particularly from small countries in Africa, Central America and the Caribbean and amounting to a significant share of the educated workforces of these nations. Docquier and Marfouk (2004, 2006) extended and refined Carrington and Detragiache's work. They offered new estimates of skilled migration rates for some 170 countries in 1990 and 190 countries in 2000 in both developing and developed countries. The Docquier-Marfouk dataset covered 92.7% of the OECD immigration stock for the relevant periods, and demonstrated that a substantial increase in the magnitude of the brain drain in Western and Eastern Africa and Central America had been experienced over the decade in question, although significant differences remained between regions and countries, with the highest brain drain rates observed in small countries in the Caribbean, Central America and Africa.

What seems clear from the available literature, including quantitative measurements thereof, is that studies tend to cover migration of the generally highly-educated across a range of employment sectors, or have a focus on specific countries or regions. Our paper aims to examine the brain drain with specific reference to elite academics on a global level. The role of the United States, as a nation that gathers up many of these talented people, is a specific focus of our paper.

Pierson and Cotgreave (2000) examined the mobility of scientists who had obtained their doctorates from the UK in 1988 and who continued to be active in their fields at the time of analysis. Each scientist was checked against the Science Citation Index (SCI) of the ISI for the period 1985-1989. All first-authored papers published during this period, together with the number of citations received by each article up to and including May 2000, were recorded. The continuing activity of researchers was established: SCI data provided a check on publication records and current country of abode. Of the 252 scientists tracked, the majority had most recently published from a UK address (62%), while 17% were now based in the US and 21% elsewhere in the world. No significant statistical difference was found between the number of articles by scientists publishing from UK addresses and those publishing from the US (2.40 ± 0.24 publications per person vs. 2.07 ± 0.43). However, the mean number of citations per article for scientists who had moved to the US was found to be significantly higher than that for UK 'stayers'. Although Pierson and Cotgreave emphasise that this does not represent conclusive proof of a significant brain drain, they nevertheless present their findings as cause for concern. They suggest that British scientists with the most potential are emigrating to the US.

Although the methodological detail provided by Pierson and Cotgreave is sketchy, their findings are nevertheless in line with those of more fully explained studies presented by Stephan and Levin (Levin and Stephan, 1999; Stephan and Levin, 2001) and Ioannidis (2004).

Stephan and Levin (Levin and Stephan, 1999; Stephan and Levin, 2001) examined whether the foreign-born and foreign-educated were disproportionately represented among individuals making exceptional contributions to science and engineering in the United States. The following illustrative criteria were used to identify data subjects: individuals elected to the US National Academy of Sciences (NAS) and/or National Academy of Engineering (NAE); authors of citation classics (journal articles identified by the Institute for Scientific Information (ISI) as having a 'lasting effect on the whole of science'); authors of hot papers ('journal articles published during the most recent two-year period that in the most recent two-month period have attracted significantly more attention than papers of the same age in the same field' (http://scientific.thomson.com/products/sw-hp/)); the 250 ISI most-cited researchers; authors of highly-cited patents; and scientists who had played a key role in the launch of bio-technology firms making an initial public offering from March 1990 through to November 1992. In the case of citation classics and hot papers, further distinctions were made between first authors and non-first authors. The resultant dataset was populated with biographical data drawn from available sources as well as via questionnaire returns. Subsequent statistical analysis of each indicator of scientific achievement revealed that, setting aside some variation by discipline, and with the sole exception of hot papers in the life sciences, elite scientists in the US were disproportionately represented by the foreign-born as well as by those educated abroad, both at undergraduate and postgraduate levels.

Bibliometric methods were also used by Ioannidis (2004) to evaluate the magnitude of the brain drain. He analysed data on 1523 of the ISI most-cited scientists for 1981-1999, using the data to determine the proportion of scientists born in a different country from where they were currently residing and controlling for the potential impact of the relative representation of different scientific fields in the sample analysed. Ioannidis found that, regardless of the analysis used, about a third of elite scientists globally had emigrated from their countries of birth (approximately three-quarters to the US), though there was considerable variability in the rate of foreign-born scientists across scientific fields and among developed countries. In the case of the latter, foreign-born highly-cited scientists accounted for about a third of scientists resident in the US, Australia, Switzerland, Israel, France and the Netherlands, with significantly lower proportions reflected in the UK (24%) and Germany (19%), a significantly higher proportion in Canada (64%), and no foreign-born highly-cited scientists in any country not belonging to an 'established market economy'[1], apart from Singapore. Notably, only 2% of US-born scientists had emigrated, against emigration rates of 20%-86% for other countries. Ioannidis further noted that "under conditions of equity at a global level, the number of native top scientists in each country should be proportional to the population" (Ioannidis, 2004: 938). Adjusting for population, it was found that the number of native highly-cited scientists was at least 75% in only 8 countries apart from the US. A further observation of concern was

[1] United Nations (1981-1986) *Annual Demographic Reports*. United Nations, Geneva.

that, using the US-born scientists as a reference point, 89% of individuals with the potential to make an impact comparable to that of the highly-cited scientists in Ioannidis' sample had not in fact attained this level of achievement. Another of his findings was that countries without an existing critical mass of native scientists – including developed nations – lost most scientists to migration.

In discussing the implications of these global estimates of elite migration, Ioannidis presents his findings as indicative of an increasing exodus of top scientists, citing the likelihood that the rate of progress of scientific growth has a direct and exponential relationship with the critical mass of scientists in a country. His nod to the advantages associated with the migration of scientists is, however, set aside in favour of a strong emphasis on the draining of scientific potential and the consequent developmental stagnation caused by these global inequalities.

The above studies provide quantitative evidence for the brain drain of highly-cited scientists. Yet methodological difficulties have been pointed out by Laudel (2003) in relation to the approaches taken by (for e.g.) Stephan and Levin and by Pierson and Cotgreave. Laudel argues that an investigation of elite mobility must necessarily solve the three methodological problems of delineating a specialty, identifying a specialty's elite and identifying international mobility and migration. The delineation of specialties is only roughly achieved by Stephan and Levin and not undertaken at all in Pierson and Cotgreave's work. In terms of ascertaining mobility, the sources of biographical data on scientists used to achieve this (e.g. the Internet, questionnaires, encyclopaedias of scientists, grant applications, etc.) are highlighted by Laudel, who cites incomplete access and incomplete data. Finally, with regard to the identification of the elite, Laudel mentions a number of issues that have been raised about the use of bibliometrics to measure scientific excellence (e.g. Van Raan, 2000; Tussen, Visser and Van Leeuwen, 2002). The issues include (given the extent of co-authorship in the sciences) the utility of citation classics and hot papers as reliable measures of the quality of a single scientist, as well as measurement problems with homonyms in the ISI data (notwithstanding some attempts to correct for this by Stephan and Levin). Nevertheless, it is worth pointing out Ioannidis' (2004) argument that "despite the debates concerning the limitations of citation analyses and the inability to find a perfect means for weighting research accomplishments (…) the number of citations is a useful surrogate of scientific impact" (Ioannidis 2004: 936). There are of course also other limitations with the studies in question – Pierson and Cotgreave's article, for example, lacks information on the nationality of the individuals included in their dataset, which arguably weakens the implications of their findings.

Laudel presents a detailed discussion of the tests conducted in her study to address the issues identified with delineation and identification of the elite and their mobility – while a range of potential solutions were covered, a combination of elite conference participation (the Gordon conferences) and an analysis of citations within the sample of active conference participants was found a promising approach (though not applicable to all specialties). A test study was conducted using the "Angiotensin" Gordon Conferences. The results from this showed that, of the 131 Angiotensin scientists investigated, 59 had always been in the US and 34 had moved to the US, out of which 16 had moved back to their countries after a temporary stay (supporting the characterisation of elite mobility as circulation) and 18 (approximately 14% of the sample) were still resident in the US, the majority of whom appeared to have migrated permanently based on their length of stay. A further 3 scientists had emigrated from the US to other countries. The remaining 35 had been resident in, or had moved to countries other than, the US. Laudel interprets her findings as confirming a putative brain drain towards the US.

This kind of research gives some credence to the contention that there is an increasing clustering of elite scientists in established centres of academe. This emphasises the degree of separation with countries in which a paucity of top researchers already exists. A perpetuation of the cycle of concentration of excellence and the corresponding scientific deficit elsewhere in the world is unexceptional. Mahroum (2000), for instance, argues that academics move close to centres of academic power and excellence, an assertion supported by empirical research undertaken by Millard (2005) which demonstrates that the location decisions of scientists are taken in the context of the prestige, visibility and networking potential of centres or clusters. As noted by Laudel (2005: 393), "…it follows that 'elite production' is autocatalytic, and that a country needs elites to generate elites".

What implications does this have for the world? It seems from the literature that documentation of the extent of the brain drain in general – not just from developing nations to established market economies but also between OECD countries – has shown an increase in the magnitude in this phenomenon. Although it is clear that there is an increasing need to factor in the impact of return migration and brain circulation, the net effect still appears to be of the 'drain' variety – particularly towards the US. Yet the implications of this are mixed. As far as return migration is concerned, there is limited evidence that this is significant among the highly skilled, unless sustained growth has preceded return (Docquier and Rapoport, 2007). For example, while less than 20% of Taiwanese and Korean Science and Engineering PhDs graduating from US universities in the 1970s originally returned to their home countries (e.g. Kwok and Leland, 1982), this proportion increased to two-thirds during the course of the 1990s following prolonged periods of significant growth in these countries (e.g. Song, 1997). Such a finding indicates that return skilled migration may be more a consequence of rather than a trigger for the development of sending nations. It also appears to be the case that, as demonstrated by Beine, Docquier and Rapoport (2007), while there is clear empirical support for the potential positives associated with elite emigration, this is limited to larger countries combining low levels of human capital and low skilled migration rates. In a comparison of 'winners' versus 'losers' on a country-by-country basis, there are markedly more of the latter – comprised particularly of small countries in Sub-Saharan Africa and Central America. More importantly, however, the latter group are also shown to experience substantive losses against the former's non-negligible gains.

Looked at from another perspective, however, it is possible to conceive of Pierson and Cotgreave's (2000) finding that the mean number of citations per article for scientists who had moved to the US was found to be significantly higher than that for UK 'stayers' as evidence contributing to the view that emigration may be beneficial for one's research. By extrapolation, the brain drain might conceivably be beneficial for the scientific community as a whole. As Millard (2005: 357) notes, researchers' location decisions are influenced by their networks, and, citing Grabher (1993) – "underlin(ing) the importance of being involved in international collaborations and networks which – partly through the mobility of researchers – provide a constant inflow of new ideas, facilitating the maintenance of the competitiveness of research groups, institutes and clusters".

Sample 1: Young Economists

We begin with information on elite young American economists. We obtained our data in a simple way: it was done by collating, and examining the patterns in, the curriculum vitae (CVs) of all assistant professors in the top-10 departments in the US. The departments are listed in Table 1. We treat these individuals as data points. Because of their youth, arguably these people give us a glimpse of the future of academic economics.[2] We find evidence of a strong ex post brain drain – a funnelling of talent into the United States – at the bachelor-degree level. The typical assistant professor has a BSc from outside the US.

Our data set on young economists was compiled in January/February 2007. In total, we obtained biographies (usually by reading CVs on the web) on 112 assistant professors. We gathered primary data on assistant professors from the ten highest-ranked economics departments in the US. The departments were chosen using www.econphd.net. Stanford University has the highest number in the sample with 16 and the University of Chicago the fewest with 6 assistant professors. In our data, there are 26 women. We documented both the research areas and research styles of the economists (not reported here but available on request). Information is missing for three assistant professors, one in Harvard, Stanford and New York University respectively, which decreases our effective sample size to 109. People's main areas of research were recorded. Data on gender were also collected.

Our results reveal ex post a striking brain drain. Only 25% of the sample had obtained their first degree in the US (Chart 1a), and 87% got their PhD there (Chart 1b). Assistant-professor positions are not evenly distributed between the genders: 24% are female and 76% male. Charts 1c and 1d give more detail on the exact

[2] We do not focus on the US to downplay the vitality and importance of young European scholars. Rather, our gathering of data stemmed from a project designed to measure international flows of scientists into the United States.

countries of origin. These findings are broadly consistent with concerns expressed, in for example Machin and Oswald (2000) and Neary et al (2003), about the growing dominance of US economics departments in academic economics research.

What is harder to say, when examining a selection of young researchers like these, is how migration and productivity are linked. For that, data on an older group of scholars is required. Our next two samples offer that.

Sample 2: Senior Physicists

Here our sample of researchers is taken from the ISI's list of highly cited physicists on www.isihighlycited.com. At the time of data collection, this contained a list of the 272 most-cited people in scholarly physics journals between 1981 and 1999. Laudel (2003, p.219) points out that the ISI's subject groupings are not broken down into specialities and therefore true in-depth analysis of 'cause and consequences' of migration cannot be analysed. However, data on these factors, such as R&D funding, does not have sufficient coverage over physics, let alone its specialities, for that depth of analysis to be undertaken and therefore the sample used is considered to be appropriate. Laudel (2003, p.223) also argues that, once specialities have been identified, citation counts alone do not uniquely identify the elite. However, Ioannidis (2004) also uses highly cited scientists in his sample and argues that they "represent a reliable sample of largely top researchers with major impact in their field" and this view is also taken in this paper. The physicists in the sample are the most 'visible' (Cole and Cole 1968, p.400) between these years. Even if they cannot be defined uniquely as the elite, they are an important group.

We created a data set on physicists. Biographical and bibliometric information for the 272 physicists was researched to determine career movements and overall career productivity. The year and place of birth, first degree and PhD were recorded - so too was country of current affiliation. Data were initially gathered from the ISI website and from the physicists' own webpages. This was followed by a further search of the Internet.

We sent emails to 146 physicists whose email addresses were identified. Of these, 63 scientists replied with further information about themselves. Sufficient data were found for 158 of the physicists, although information on first degrees is only available for 150 of them. Further data for the countries of origin and current affiliation was collected from OECD Statistics. All variables were averaged between 1970 and 2006 to cover the main period during which the physicists were active, the mean year of first degree being 1968 and 1973 for PhD. Data were available for 21 countries[3]. Data for the missing countries[4] were not collected from other sources (in order to maintain consistency in data-gathering).

These physicists are currently affiliated to 16 different countries. This leads to some language difficulties. Websites could only be read perfectly in English and Italian, although some online translators were used. Emails were sent in English, and this may have affected response from those in non-English speaking countries. To examine a possible bias towards English-speaking countries, the proportions of the final 158 physicists are compared to those of the original 272. The USA is the only substantially overrepresented country, with 17 more physicists; and Japan is underrepresented by 9 physicists. The other countries varied from their expected number by one or two, although in some cases this is still a large portion of their representation. There is no way to solve this problem, and the response rate (43%) was similar to those of previous studies (Laudel 2003, p.224). This is considered when interpreting later results.

Chart 2 reveals a remarkable funnelling of scientific talent into the United States. Of our 158 highly-cited scientists, 70% were born outside the USA. At the BSc level of their education, that had fallen to 57% of these people being outside America. By the year they came to do their PhD, the majority of these scientists were in the United States. The 70% had become 45%. Finally, when we observe where they work today, only 34% are working outside the United States.

---

[3] Australia, Austria, Canada, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Korea, New Zealand, Poland, Spain, Sweden, Switzerland, Turkey, UK and USA

[4] Israel, Argentine, Chile, China, India, Russia, Brazil, Iran, Taiwan

Charts 3a and 3b classify the data by region of donor country and recipient country. As can be seen, in terms of per-capita the big importers of brain power in the world are Switzerland and the USA. This may be because of the high professorial salaries paid in these nations, or because of generous scientific funding, or for a mixture of these reasons. Charts 4 and 5 are illustrations for Germany and the UK respectively. Charts 6a and 6b give further detail.

We would like to know whether it is the most talented who tend to leave a country. The next issue in data collection, therefore, was in calculating productivity levels. The ISI Web of Knowledge was used to calculate the h-index (as a reminder, an h-index of 20, say, means that a researcher has written at least 20 papers that are each cited at least 20 times). This required us initially to identify each physicist's publication list, which can be problematic when many physicists have similar names. Laudel (2003, p.232) examines this issue and carried out further analysis of publication lists and co-authors to ensure that only the correct scientist's work was included. In our study, each individual was considered separately. In some cases, initial inspection showed no problems: physicists had identified how many papers they had published. However, in some cases, further examination of the exact names used on published papers and identifying the institutions worked for had to be undertaken in order to obtain the publication list. In two cases, physicists were eventually removed from our sample due to our lack of confidence in the measurements. In bibliometrics, total citation counts often contain errors caused by homonyms. The impact of misspecification is considered less problematic with the h-index: the probability of a second physicist with the same surname and initials appearing within the relatively small selection of papers which affect the h-index score is lower than for an entire list of people and publications.

The sample of 158 physicists contains 1 female, and 8 of our 158 have won Nobel Prizes (see appendix 1, tables 15a and 15b). Of the total number, 61.4% have worked in multiple countries and 97.5% have worked in multiple institutions. Currently, 76% are affiliated to a university, 17% to other types of public institutions and 7% are in private institutions. Regarding the span of their careers, 96% have, at some point, worked in academia since obtaining their PhD; 54% have experienced another type of public institution; and 47% have spent a period in the private sector. The average number of institutions worked in is 6.03, and the average number of countries worked in is 2.41, with maximum values of 25 and 12 respectively. These ISI Highly Cited Researcher physicists were born in 32 different countries. They studied for their first degree in 30 different countries. They did PhDs in 22 countries. They are presently located in only 16 countries. This shows a funnelling, at the country level, of approximately 50% from birth to the present day.

The percentage of physicists present now in each country reveals that the principal funnelling effect is towards the USA. Table 2 demonstrates that at birth, 29.7% of physicists were in the USA, which increases to 43.4% at first degree, 55.1% at PhD and to 67.1% presently. The proportion in the 2^{nd} and 3^{rd} ranked countries falls by approximately 3 percentage points from birth to present day, with the share in the rest of the world falling dramatically from 50% at birth to only 19.6% presently.

Overall, 44% of scientists have moved since birth (see Table 3). These findings are only a little different from those of Ioannidis (2005), who found that 50% of his physicists had moved since birth. The difference is partly attributable to the larger sample size in this paper: 158 scientists compared to 46 scientists in Ioannidis' work.

Summary statistics for these people's citation levels can be seen in Table 4. The average h-index in the sample is approximately 59, with minimum and maximum values of 22 and 115 respectively. In order to examine the effect of co-authorship, the number and countries of the co-authors of ten randomly selected physicists in the sample was examined (results not reported but available upon request). The number of co-authors for each of the ten varies extraordinarily from approximately 3 to 366 and the number of affiliated countries from 1 to 7. Although there is a tendency for those with more co-authors to have higher h-indexes, the evidence is not substantial. This seems to reinforce the previous decision to not adjust h-indexes for co-authorship.

These h-index results were compared with the total number of published papers, total citations, and average citation count. There is no correlation with average citations per paper, a significant correlation of 0.40 with total number of published papers, and of 0.54 with total citations.

Chart 7 shows that those who currently work in the USA have an h-index which is on average 5.71 points higher than those in the non-USA institutions. This difference is statistically significant at the 5% level. Breaking the non-USA sample down further leads to very small sample sizes, unfortunately, which makes statistical tests less effective. There are several possible reasons for this apparent higher productivity, one of which is that people working in the USA in a dense academic market cite each other more often for purely sociological reasons.

Are movers of higher quality as physicists than those who choose to stay in their own country? Separating the sample into those who have migrated and those who have not – since either birth, BSc or PhD – shows no statistically significant difference in productivity levels (see Table 5), although there is no perfect way of measuring the productivity levels in the alternative situation. This result tentatively suggests that the act of migration itself may not increase productivity (see, however, Appendix 2 for some qualitative interview insights from scientists within this sample).

Sample 3: Senior Bio-scientists

Our third group of researchers is drawn from bio-science. This group of researchers numbers 163 people. More precisely, they are all ISI Highly Cited Researchers in the ISI field defined as 'Biology and Biochemistry'. Moreover, this time our sample is taken entirely from scientists currently working in the United States. Hence the sampling is somewhat like that for our economists, but with the additional feature that all had to be HiCi researchers to be included.

Chart 8a documents data on all those in our sample who moved into the USA. The chart summarises, for the individuals on whom we have information, the cross-national distribution of their countries of birth. As with physics, these talented individuals come from a host of different birth nations. It can be seen in Chart 8a that Japan is the major donor country (with 7 bio-scientists moving from this country), followed by the UK and Canada (with 5 each). Chart 8b captures the movement data on those who went to the United States after their PhD.

In Chart 9, we plot the numbers of bio-scientists, at different stages of their professional lives. The general pattern is reminiscent of those for the economists and physicists. Once again, North America soaks up, at each successive stage, a larger and larger number of the elite science researchers. For our sample:

% bio-scientists working now in the USA and born in the USA: 60%
% bio-scientists working now in the USA and BSc in USA: 70%
% bio-scientists working now in the USA and PhD in USA: 72%
% bio-scientists working now in the USA: 100%

Greater detail is set out in Chart 9.

<u>3. Funnelling and h-index Productivity</u>

In Tables 6a and 6b, we take a closer look at migration at different stages of a person's professional career. We capture this with what we call a *funnelling coefficient*. This measures the proportion of researchers lost from the country at that career stage. Hence, in Table 6a, 15% of people who are now highly-cited physicists leave their country of birth to do their undergraduate degree; 17% do the equivalent at the PhD stage; 25% do so in between PhD and where they currently work. Table 6b is not exactly comparable, because it draws only on scientists now in the United States, but it gives the same kind of picture. Table 7, on highly-cited bio-scientists, reveals something broadly similar, but interestingly the extent of the funnelling appears rather less than in physics. Whether this reduced mobility might be because of larger set-up costs of laboratories in biological science, as compared to that in physics, can only be one speculation.

An important intellectual issue in the study of the brain drain is whether it might be good for world science for talented people to move to the rich science-intensive nations such as the USA. The argument here is a natural one (and was put forward in the Financial Times in 2007 by Larry Summers, formerly president of Harvard University – in economics this is termed an 'externalities argument'). If scientists become more creative when working with other top people, perhaps by sparking off each other, then it may be beneficial to the global community, in the long run, to have an elite brain drain. Individual donor countries may lose, goes this argument, but mankind as a whole gains from the new ideas so fostered. Oswald (2007b), by contrast, raises the possibility that if most researchers go to the USA it may lead to too much homogeneity of intellectual approach.

Tables 8, 9 and 10 report the h-index values of our ISI Highly Cited Researchers in both physics and bio-science. The tables break down the numbers into movers and stayers: these are the people represented in the Moved and Remained columns respectively. Intriguingly, we cannot find statistically significant differences across these kinds of movers and stayers. A similar kind of result is captured in Chart 10.

Table 11 takes a different look at this issue for the case of the physicists. Here it can be seen that the h-indexes of scholars do not greatly vary across continents.

Many factors influence the productivity of outstanding scientists, so it is natural to ask whether, once other influences are held constant, we can detect an effect from having migrated to a different country. In this spirit, a more formal test than earlier is set out in Table 12. This table provides two sets of regression equations. In the upper half of the table, the dependent variable is the h-index of the highly cited physicists in our sample. In the lower half of Table 12, the dependent variable is the total citations (summed over a lifetime) of these physicists. The independent variables are listed vertically. It can be seen – as we add extra variables, going from the left-hand columns to the right-hand columns – that the country in which an individual scholar works does not prove to be a statistically significant influence on his or her measured productivity. The only significant predictor of citations, whether in the form of an h-index or as a total amount, is the number of years since a person had completed their PhD. There is a chance here that Type II errors are being made. At 138, the sample size is fairly small, and those working in the USA have, according to the penultimate column of the upper half of Table 12, an h-index that is approximately 14% higher than others; but this number is not statistically significantly different from zero at the 5% level.

What Table 12 seems to show us is that elite brain-drainers are not noticeably better or worse than those elite scientists who choose not to leave their country. Whether larger data sets than ours might in the future alter such a conclusion remains, of course, to be seen.

Chart 11 explores data on another issue, which we call *clustering*. It examines the degree to which top researchers are clustered, in particular subject areas, in the world's universities. We provide evidence that this is common. In other words, universities that have one highly cited mathematician or chemist are disproportionately likely to have another in that same field (and this is not merely because they are large or famous universities). This kind of clustering is actually clear informally when one goes through the web pages of www.isihighlycited.com.

To provide a more systematic check, Chart 11 examines a sample of universities with either 2 or 3 ISI Highly Cited Researchers in them. If people are randomly distributed by subject, a duplication of field within this sample should be a rare finding. The reason is that there are 21 different scientific areas listed in the highly-cited website – therefore, given randomness, the probability of any particular field being found is, per person, only approximately 5%. Two brilliant people in the same area would only occur by fluke. Yet Chart 11 shows that the statistically expected number of researchers is not found in the data. Instead, a strong degree of clustering occurs.

If we examine universities with 2 so-called HiCis, it is the case that for one-third of the time, those two individuals are both in the same scholarly area. Randomness, by contrast, would predict that the probability of this would be 1/21. In universities with 3 HiCis, it is the case that for more than half the time, at least two of those people are in the same field. Under the null hypothesis of randomness, this proportion should be approximately only 1/7. For the figures, see Tables 13 and 14.

The import of all this is that the world's universities are, whether through accident or design, specialising in whom they hire. Some universities have heavy concentrations of elite researchers in subject X and none in subject Y, while others have those rare individuals concentrated within subject Y and nobody in subject X. It is not possible to know exactly why this happens. But a plausible part of the explanation is that brilliant people are attracted by the existence of top scholars in their particular field of intellectual endeavour. The result is a highly uneven spread of talent, by field, across universities.

4. Strategies for Universities and Governments

University strategies

There are a number of reasons that might lead us to assume that it is in the interest of 'world-class' leading universities to consider the implications of the mobility, funnelling and clustering of the top researchers. A key, if not *the* key, characteristic of a world-class university is the quality of its academic and research staff. This quality drives reputation and influence with the funders of research, within the global higher education and research community, with national and international governments and agencies; it enhances a university's ability to recruit the best staff and students; it helps attract donors and commercial enterprises to their doors.

Our analysis has used Highly Cited researchers as a proxy for the world's best researchers. This indicator, alongside other citation indices, is used within the major world rankings [5]. As these rankings gain publicity and credibility, universities are turning to analysis of their own citation position. They perceive the potential for such rankings as a major publicity tool to enhance global reputation and to attract and retain the best researchers. Just as national rankings lead to game playing by institutions and manipulation of statistics, there is no reason to think international rankings will be immune.

So how might world-class universities react strategically to the evidence of funnelling and clustering of top researchers? There are three major strategies:

- i) Grow your own (identify and retain the best researchers from an early stage)
- ii) Attract the best
- iii) Collaborate with the best

[5] Shanghai Jaio Tong uses Highly Cited, Nature and Science; THES-QS uses citations.

i) Growing your own

Our analysis has suggested that institutions and countries which attract the best researchers early on in their careers will have a higher chance of retaining them in their country of study[6]. Institutions may decide to focus on strategies which will produce competitive demand for PhD or postdoctoral funding opportunities and nurture their best staff within their own research communities. What the analysis does not demonstrate, however, is the sheer scale of investment in the next generation's researchers required to produce one world-class researcher. By definition, Highly Cited researchers are a rare breed. This strategy is risky in terms of identifying the next generation of Highly Cited top researchers. It depends on significant amounts of funding being available to invest in a competitive scheme, and relies on an existing community of excellent researchers to attract the most excellent students and early career research staff.

However, in terms of supply, there is evidence of growing internationalisation of university staff, demonstrating increasing mobility. A recent analysis in the UK identified that 19.1% of university academic staff in post in 2005/06 were non-UK nationals. [7] A recent survey amongst Commonwealth countries provided an average of 12% of foreign nationals in the academic workforce.[8] This is likely to be a consequence of the huge increase in mobility of students, funded from massive investment into higher education from growing economies in South East Asia, India and Africa.

ii) Attracting the best

By targeting the best researchers, universities invest in a known quantity. The risk of identifying potential is reduced. Universities could target Highly Cited researchers, or

---

[6] There are also a number of other studies which have identified this phenomenon on a broader scale. An OECD report in 1999 indicated that 47% of foreign-born PhD graduates who studied in the US remained in the US. A recent report (2007) from the Chinese Academy of Social Sciences in Beijing claimed that 70% of Chinese-born graduates who studied overseas have not returned to China.

[7] UUK Policy Briefing (2007): *Talent wars: the international market for academic staff*

[8] Association of Commonwealth Universities (2007) *2006-07 Academic Staff salary survey*, London:ACU

identify potential through analysis of individuals' citations alongside their other research achievements. This is an expensive strategy and also a highly competitive strategy. Academic salaries need to be globally competitive and investment in research infrastructure will also be necessary. Top researchers know their worth and will also be likely to consider a range of other factors such as the staff in the groups and department in the institution, and quality of life factors may increasingly come in to play with researchers in mid-career.

Universities pursuing this strategy must ensure that academic recruitment processes are truly global and truly competitive. Parochial and paternalistic advertising, appointment and promotion structures need to be addressed to ensure that institutions are able to attract the very best staff.

The analysis on clustering of Highly Cited researchers suggests that institutions may benefit from targeting individuals from within particular subject areas, building on existing strength. Appointment strategies may seek to attract whole groups of research staff to achieve this.

iii) Collaborating with the best

In recent years, critique of the 'brain drain' phenomenon has developed into the notion of 'brain circulation'. This suggests that mobility is such that researchers may go back and forth between countries and develop global research networks which are not highly dependent on the location of individual institutions. Given that the first two strategies are likely to be expensive and influenced by current reputation and staffing, a third strategy is to encourage and invest in short-term and visiting fellowships and scholarships, with a view to promoting longer term collaboration with current university staff and development of a continuing relationship and identification with the receiving university.

A report by Evidence Ltd[9] identified that 45% of Highly Cited researchers currently located in the UK have spent time overseas during their careers. This is a higher percentage of mobility than a similar comparison with the US, but is lower than that found in Australia and Canada.

Fractional appointments held by an individual in two or more countries are not unusual and increasingly PhD and post-doctoral opportunities may be held collaboratively. This strategy enables universities to grab a piece of the action and benefit from the interaction with the top researchers, without a significant up-front investment. It requires a longer-term game which may bring some initial 'quick-wins'.

Governmental strategies

Strategies of universities cannot, however, be considered in isolation from governmental policies and strategies. These will influence the ability of universities to act strategically and may determine the level of funds available to invest in those strategies.

Higher Education has increasingly been the focus of economic, not just education, policies. Global competitiveness has led to increased targets for expenditure on research and development in key world economies: e.g. the EU target is 3 per cent of GDP by 2010; China's target is 2.5 per cent by 2020. A highly qualified and skilled workforce is regarded as essential to a globally competitive economy. A globally competitive higher education system is regarded as a way to ensure the supply of such a workforce, as well as being a major contributor to research and development in terms of its staff's output.

Whilst developing countries have for many years invested in a skilled workforce by sending their best students abroad, governments have realised that this carried a significant risk that these graduates may remain overseas. Governments therefore have turned to strategies to encourage students to remain at home (e.g. in India where

[9] Bekhradnia B, and Sastry T, (2005) *Brain drain:migration of academic staff to and from the UK*, HEPI

investment has focused on securing 5 Indian universities that are regarded as globally competitive) or to return. Recent policies in China and Singapore have been focused on providing attractive packages for returning graduates and skilled workers, e.g. new regulations were introduced in China in March 2007 to provide exemptions from household registrations for senior scientists, engineers and corporate managers.

Other governmental strategies in evidence include focusing investment on centres of excellence (to promote clustering) e.g. CERN, the world's largest particle physics laboratory, in Geneva, and strategies to exploit mobility e.g. Marie Curie fellowships in the European Union.

Governmental immigration strategies can also influence the ability of institutions to attract world-class researchers. The increase of the cap on the numbers of temporary visas available for highly skilled professionals by 80,000 per annum approved by US Congress in 2000 provided a boost for enabling staff mobility at a time of expansion for US universities (although it failed to achieve its target because of restrictions post 9/11). However, restrictions on dual nationality in a number of African states have been regarded as discouraging the return of highly skilled workers.

Dependency on government funding will also have a significant impact on universities' ability to act competitively. Issues such as national salary frameworks and employment conditions are significant, but governments may also seek to influence behaviour to restrict or boost mobility.

Finally, but significantly, governmental policies on the permitted parameters of research will influence the ability of institutions to attract the best researchers. Restrictions reflecting ethical, religious or political ideology may deter or simply prevent the best researchers from reaching a university, whatever the other attractions on offer. When the US clamped down on stem-cell research, a number of leading stem-cell researchers left for overseas.

Institutions still find they have to work within national contexts in an increasingly globally competitive market.

5. Conclusions

This paper is a study of the elite brain drain. We hope that the paper's findings will be of interest to those concerned with the state of world academic research, with brain drain issues, and with long-range university planning. Our paper is unusual within the literature because we concentrate on the migration choices of particularly distinguished scientists and economists.

Partly by contacting the scientists directly, partly by using the source www.isihighlycited.com, and partly by the acquisition through web searches of CVs on individuals, we have constructed data sets on some of the world's leading thinkers in three fields of inquiry. Our data cover 112 young economists, 158 senior physicists, and 163 senior bio-scientists. These data sets are not huge, but that is inevitable when the focus is on rare and iconoclastic individuals. Many of our data points are people who are likely to win Nobel Prizes in their fields.

The background to this project is the attention now paid to the hierarchy of universities in the world. A growth in league tables, in this case across international universities, seems likely to encourage new and explicit status-ladders (indeed that is perhaps their purpose). Like other human beings, scientists care about status. At one level this is all just one more sign of globalisation. But the phenomenon of world league tables could lead to greater emphasis among researchers on where they work rather than what scientific research they do. Something like this has already been seen elsewhere in academia in the form of growing concern among researchers with the prestige of particular journals per se – what some have called an obsession with labels[10] themselves – rather than about the quality of scientific discovery itself. In an increasingly electronic and globalised world, it might not be a surprise to see eventually an equivalent obsession with the prestige labels attached to university names. If so, that is likely to intensify existing mobility and global brain drain pressures.

[10] See, for example, Monastersky (2005), Starbuck (2005) and Oswald (2007a) - all of whom point out that prestige journal labels are poor sufficient-statistics for quality and thus can mislead.

The paper's main findings are the following:

- There is evidence of a brain drain in elite thinkers. We document a remarkable funnelling of talent from a large number of donor countries into a small number of receiving countries.
- Among ISI Highly Cited Researchers in the field of physics, for example, nearly 50% of individuals do not work in the country in which they were born. We document similar tendencies among elite bio-scientists and young economists.
- In economics, there exists a striking exodus, after the bachelor-degree stage, towards the United States. We study this by collating scholars' CVs. We show that approximately 75% of the assistant professors currently working in the top-10 US departments are in a sense not Americans. They did their undergraduate degrees in other countries.
- At every educational stage, strong funnelling occurs – particularly but not exclusively towards the United States and Switzerland. These nations are, per capita, the world's greatest net-importers of scientific brains.
- In our sample of physicists, there appears not to be a statistically significant difference in quality – we measure this mainly with the h-index – between those who move and those who stay. This differs from the general claim of Pierson and Cotgreave (2000) who focused, perhaps strangely, on citations per paper (their paper in Nature also noted, without comment, that stayers actually write more papers).
- Funnelling occurs at each stage in scientists' educational and professional careers. The coefficient of funnelling is approximately 0.2 among highly-cited physicists and 0.1 among highly-cited bio-scientists. Until more research on other samples is done, these numbers should be treated cautiously.
- There is striking evidence that elite researchers tend to cluster together. Individual universities, in other words, often have their HiCis in only a few fields. As an example, in universities with only 2 ISI Highly Cited

> Researchers, we show in the paper that one third of the time both those people are in the same discipline.

When distinguished scientists move, it is likely to be costly for donor countries and a boon to receiving nations. But it seems important to think more broadly. As Larry Summers has argued, allowing science researchers to cluster together may provoke positive externalities: people may spark off each other to the benefit of the whole academic discipline. Perhaps the discovery of DNA would have been slowed if the American James Watson had not been in Cambridge to work with the Englishman Francis Crick.

Is the global brain drain a major problem for the world, a minor problem for the world, or perhaps even a benefit to mankind? Such a question is not easy to answer. Our data, however, fail to find a clear productivity difference (some years later) between the elite movers and the elite stayers. This is consistent with, although does not unambiguously prove, the idea that the brain drain creates no significant beneficial externalities for science. Those who advocate the brain drain as good for humanity as a whole need to show that moving makes a migrating scientist do better science. This may be true, and much more research, especially longitudinally, is needed. But we have not found evidence for such a claim.

References

Beine, M., Docquier, F. and Rapoport, H. (2001), "Brain drain and economic growth: theory and evidence", *Journal of Development Economics*, 64(1), pp.275-289.

Beine, M., Docquier, F. and Rapoport, H. (2007), "Brain drain and human capital formation in developing countries: winners and losers", *Economic Journal*, forthcoming. [Working version of paper accessed online at http://www.ires.ucl.ac.be/CSSSP/home_pa_pers/docquier/articles.htm on 25 June 2007]

Bekhradnia, B. and Sastry, T. (2005), *Brain Drain: Migration of Academic Staff to and from the UK*. Higher Education Policy Institute, UK.

Bhagwati, J.N. and Hamada, K. (1974), "The brain drain, international integration of markets for professionals and unemployment: A theoretical analysis", *Journal of Development Economics*, 1(1), pp.19-42.

Carrington, W.J. and Detragiache, E. (1998), "How big is the brain drain?", IMF Working Paper No. 98/102, Institute for the Study of Labor, Washington, DC.

Carrington, W.J. and Detragiache, E. (1999), "How extensive is the brain drain?", *Finance and Development* 36(2), pp.46-49.

Commander, S., Kangasniemi, M. and Winters, L.A. (2004), "The Brain Drain: Curse or Boon? A survey of the literature", in Baldwin, R.E. and Winters, L.A. (eds.), *Challenges to Globalization: Analyzing the Economics*, University of Chicago Press, pp. 235–278.

Docquier, F. and Marfouk, A. (2004), "Measuring the international mobility of skilled workers (1990-2000)", *Policy-Research Working Paper Series No. WPS3381*, The World Bank: Washington D.C.

Docquier, F. and Marfouk, A. (2006), "International migration by educational attainment (1990-2000)", in Ozden, C. and Schiff, M. (eds), *International migration, remittances and the brain drain*, Palgrave Macmillan.

Docquier, F. and Rapoport, H. (2007), "Skilled migration: The perspective of developing countries", in Bhagwati, J. and Hanson, G. (eds), *Skilled migration: prospects, problems and policies*, The Russell Sage Foundation: New York, forthcoming. [Accessed online at http://www.ires.ucl.ac.be/CSSSP/home_pa_pers/docquier/filePDF/BhagwatiHansonChapter.pdf on 25 June 2007]

European Commission. (2002), "More research for Europe: Towards 3% of GDP." Communication from the Commission, COM(2002) 499 final, p.22.

Gaillard, J. and Gaillard, A.M. (1997), "The international mobility of brains: exodus or circulation?", *Science Technology and Society*, 2(2), pp.195-228.

Grabher, G. (1993), "The weakness of strong ties", in Grabher, G. (ed), *The Embedded Firm: On the Socio-economics of Industrial Networks*, Routledge: London.

Hirsch, J. E. (2005), "An index to quantify an individual's scientific research output", *Proceedings of National Academy Science*, 102(46), pp. 16569-72.

Ioannidis, J.P.A. (2004), "Global estimates of high-level brain drain and deficit", *The Journal of the Federation of American Societies for Experimental Biology*, 18, pp.936-939.

Hamada, K. (1977), "Taxing the brain drain: A global point of view", in Bhagwati, J. (ed), *The New International Order*, M.I.T. Press: Cambridge, Massachusetts.

Johnson, J. M. and Regets, M. (1998), "International mobility of scientists and engineers to the United States - Brain drain or brain circulation?" National Science Foundation (June). NSF 98-316.

Kugler, M. and Rapoport, H. (2007). “International labor and capital flows: complements or substitutes?”, *Economics Letters*, 94(2), pp.155-162.

Kwok, V. and Leland, H.E. (1982), “An economic model of the brain drain”, *American Economic Review*, 72(1), pp.91-100.

Laudel, G. (2003), “Studying the brain drain: Can bibliometric methods help?”, *Scientometrics*, 57(2), pp. 215-237.

Laudel, G. (2005), “Migration currents among the scientific elite”, *Minerva*, 43, pp.377-395.

Levin, S.G. and Stephan, P.E. (1999), “Are the foreign born a source of strength for U.S science?” *Science*, 285, pp.1213-1214.

Machin, S. and Oswald, A. J. (2000), “UK economics and the future supply of academic economists”, *Economic Journal*, 110, pp. F334-F349.

Mahroum, S. (2000), “Scientists and global spaces”, *Technology in Society*, 22, pp.513-522.

McCullock, R. and Yellen, J.T. (1977), “Factor mobility, regional development and the distribution of income”, *Journal of Political Economy*, 85(1), pp.79-96.

Meyer, J.B. (2001), “Network approach versus brain drain: Lessons from the diaspora”, *International Migration*, 39(5), pp. 91-110.

Millard, D. (2005), “The impact of clustering on scientific mobility”, *Innovation: The European Journal of Social Science Research*, 18(3), pp.343-359.

Monastersky, R. (2005), “The number that is devouring science”, *The Chronicle of Higher Education*, Issue: October 14.

Mountford, A. (1997), “Can a brain drain be good for growth in the source economy?”, *Journal of Development Economics*, 52(2), pp.287-303.

Neary, J. P., Mirrlees, J. A. and Tirole, J. (2003), “Evaluating economics research in Europe: An introduction.” *Journal of the European Economics Assocation*. 1, pp. 1239-1249.

Oswald, A.J. (2007a), “An examination of the reliability of prestigious scholarly journals: Evidence and implications for decision-makers”, *Economica*, 74, pp.21-31.

Oswald, A.J. (2007b), “Comment on Summers on Life Sciences”, *Financial Times*, January 29th.

Pierson, A.S. and Cotgreave, P. (2000), “Citation figures suggest that the UK brain drain is a genuine problem”, *Nature*, 407, pp.13.

Royal Society (1963), “Emigration of scientists from the United Kingdom: Report of a committee appointed by the Council of the Royal Society”, Royal Society: London.

Saint-Paul, G. (2004), “The brain drain: Some evidence from European expatriates in the United States”, IZA Discussion Paper series; Institute for the Study of Labour (September).

Song, H-Z. (1997), “From brain drain to reverse brain drain: three decades of Korean experience”, *Science, Technology and Society*, 2(2), pp.317-345.

Starbuck, W.H. (2005), “How much better are the most-prestigious journals? The statistics of academic publication”, *Organization Science*, 16, pp.180-200.

Stephan, P.E. and Levin, S.G. (2001), “Exceptional contributions to US science by the foreign-born and foreign-educated”, *Population Research and Policy Review*, 20, pp.59-79.

Summers, L.H. (2007), “America must not surrender its lead in life sciences”, *Financial Times*, January 29th.

Tussen, R.J.W., Visser, M.S. and Van Leeuwen, T.N. (2002), “Benchmarking international scientific excellence: Are highly cited research papers an appropriate frame of reference?”, *Scientometrics*, 54, pp.381-397.

Universities UK (2007), “Talent wars: the international market for academic staff”, Policy Briefing, July.

Van Raan, A.F.J. (2000), “The Pandora’s box of citation analysis: Measuring scientific excellence – The last evil?”, in Cronin, B. and Atkins, H.B. (eds.), *The Web of Knowledge*, Information Today, Inc.: Medford, New Jersey.

Woods, M. (2003), “Europe slow in stemming ‘brain-drain’ to America”, Post-Gazette National Bureau (October 20th) URL: www.post-gazette.com.

Table 1: The Data Set on Young American Economists

Data on Assistant Professors in Major US Departments of Economics

Sample Size: 112

Ranking of Economics Departments			
Ranking	**Name of University**	**Location of University**	**Number of Assistant Professors in Our Data Set (Total: 112)**
1	Harvard University	Cambridge, Massachusetts	14
2	University of Chicago	Chicago, Illinois	6
3	Massachusetts Institute of Technology (MIT)	Cambridge, Massachusetts	9
4	University of California	Berkeley, California	12
5	Princeton University	Princeton, New Jersey	11
6	Stanford University	Palo Alto, California	16
7	Northwestern University	Chicago, Illinois	12
8	University of Pennsylvania	Philadelphia, Pennsylvania	12
9	Yale University	New Haven, CT	9
10	New York University	New York City, New York	11

Chart 1a: Distribution of USA-based Economists: Country of BSc

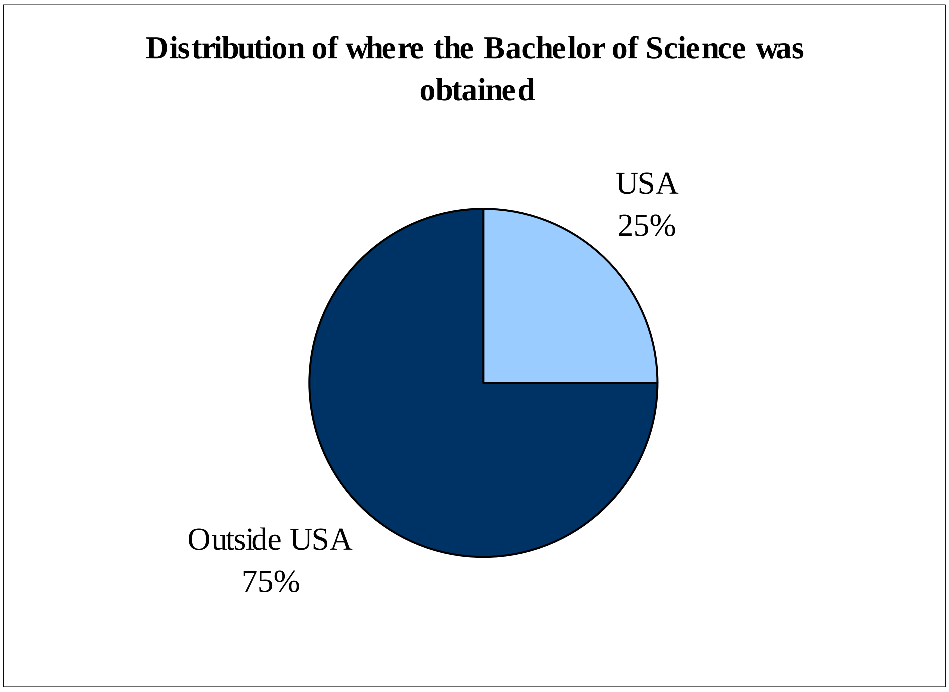


Chart 1b: Distribution of USA-based Economists: Country of PhD

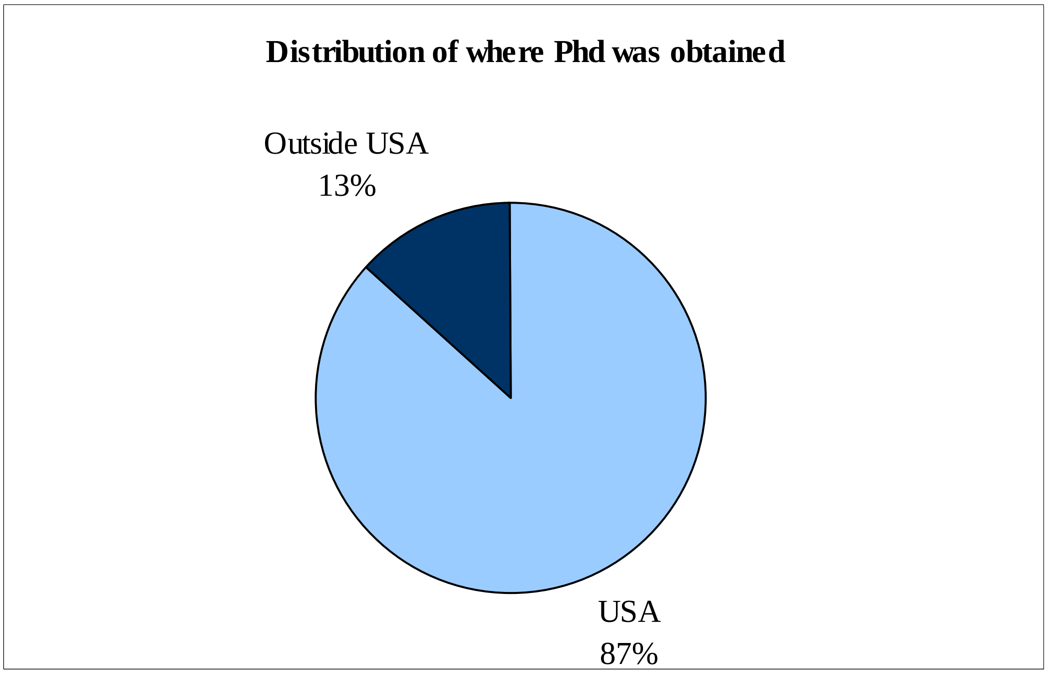


Chart 1c: USA-Based Economists: The Country of Their BSc

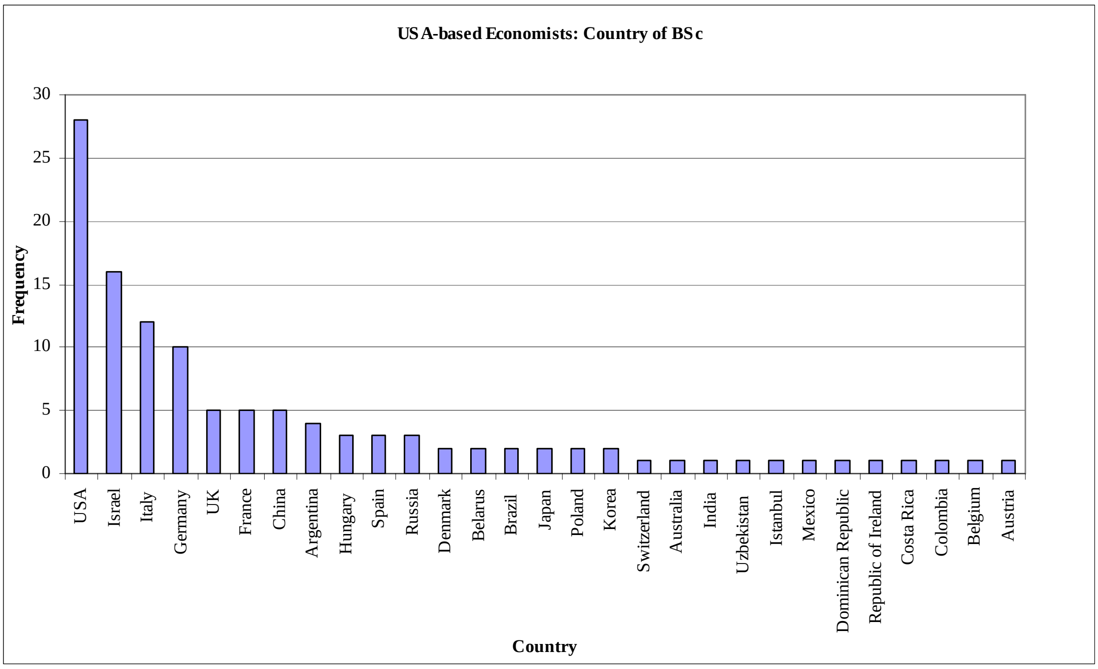
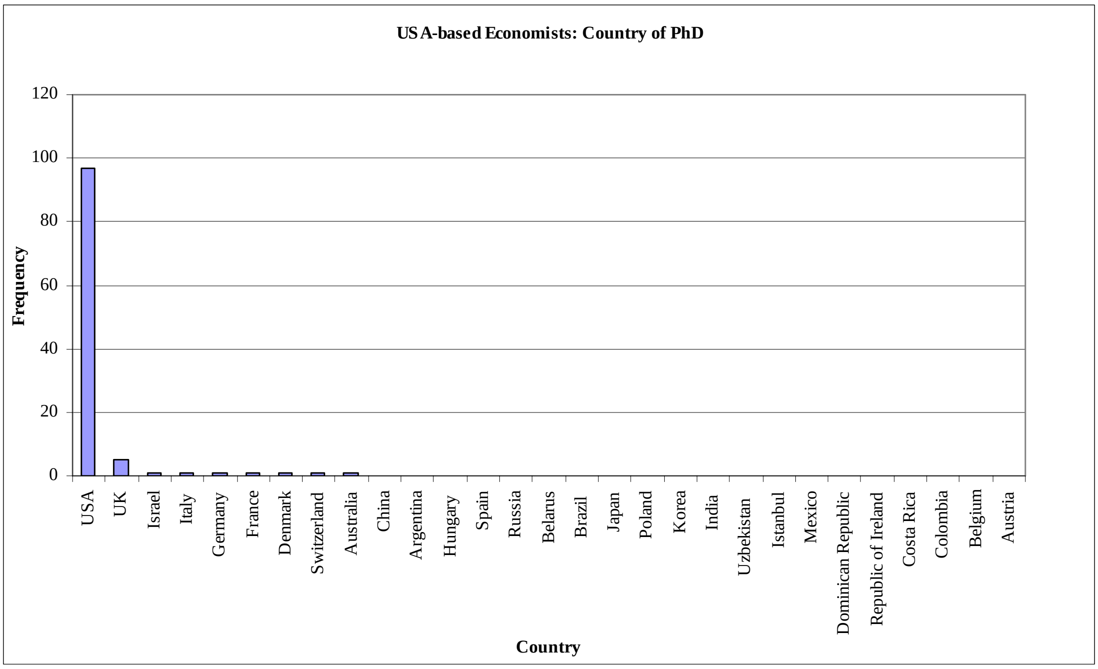


Chart 1d: USA-Based Economists: The Country of Their PhD



Note: Economics Assistant Professors currently at Top 10 US Institutions gained their BSc within a wide range of countries. However their PhDs were overwhelmingly obtained in the USA.

Chart 2: Funnelling into the USA: The Movement of Highly-cited Physicists

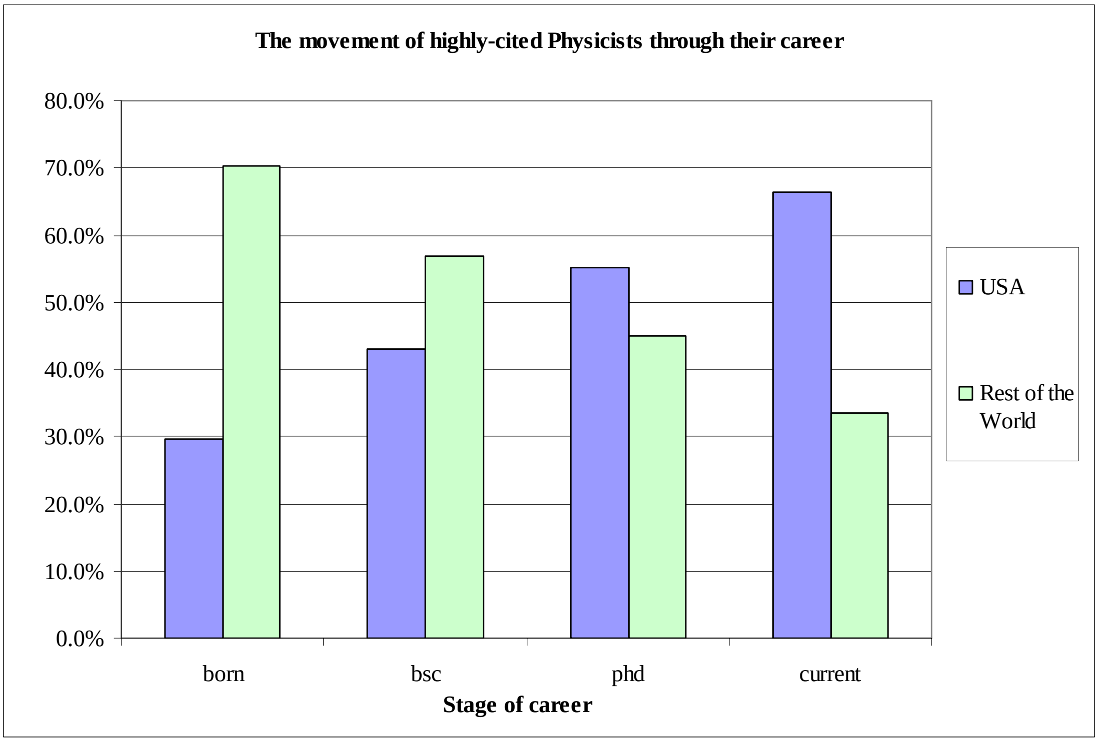
Sample Size: 158

Error: Country of birth missing: 20 (12.7%)

BSc country missing: 7 (4.4%)

PhD country missing: 0 (0%)

Current country missing: 0 (0%)



Actual figures for Chart 2 above

Stage	Percent in USA	Percent in Rest of World
Born	29.7	70.3
BSc	43.0	57.0
PhD	55.1	44.9
Current	66.5	33.5

Chart 3a: Highly-cited Physicists: Gain and Drain by World Region

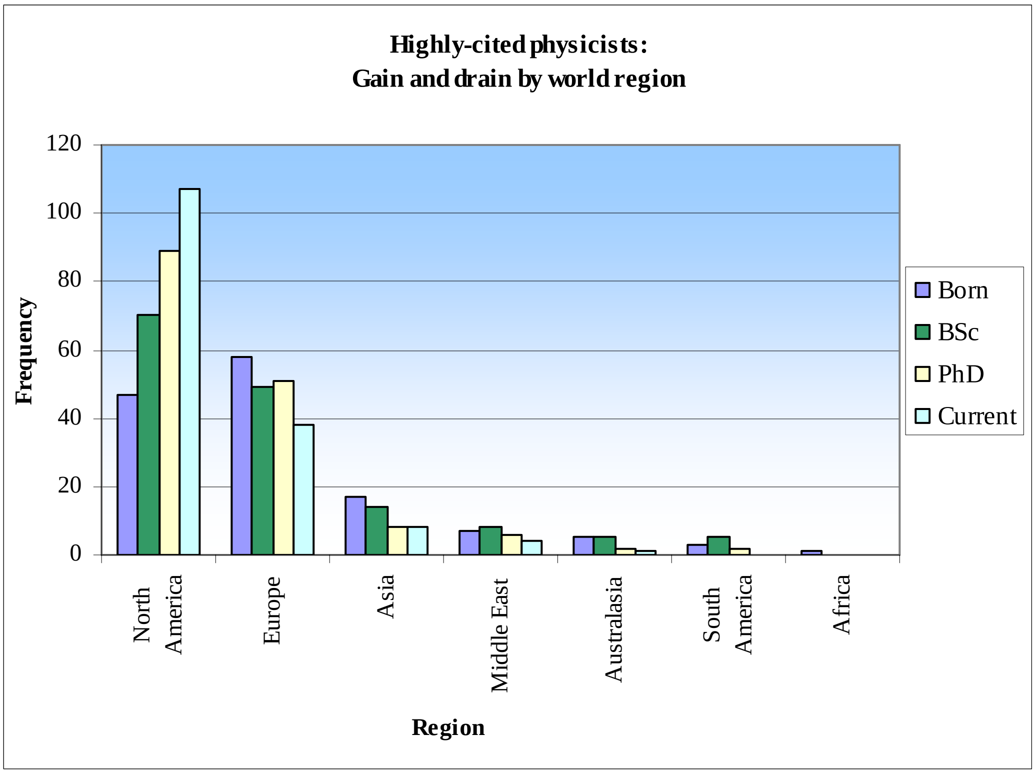
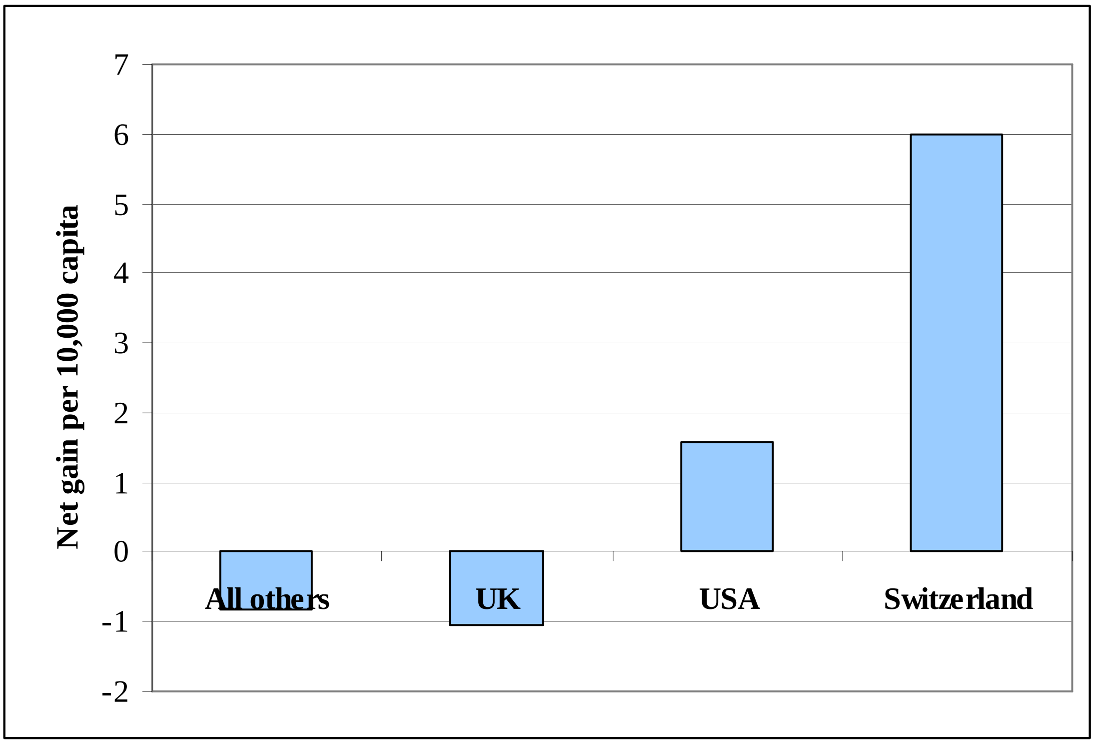
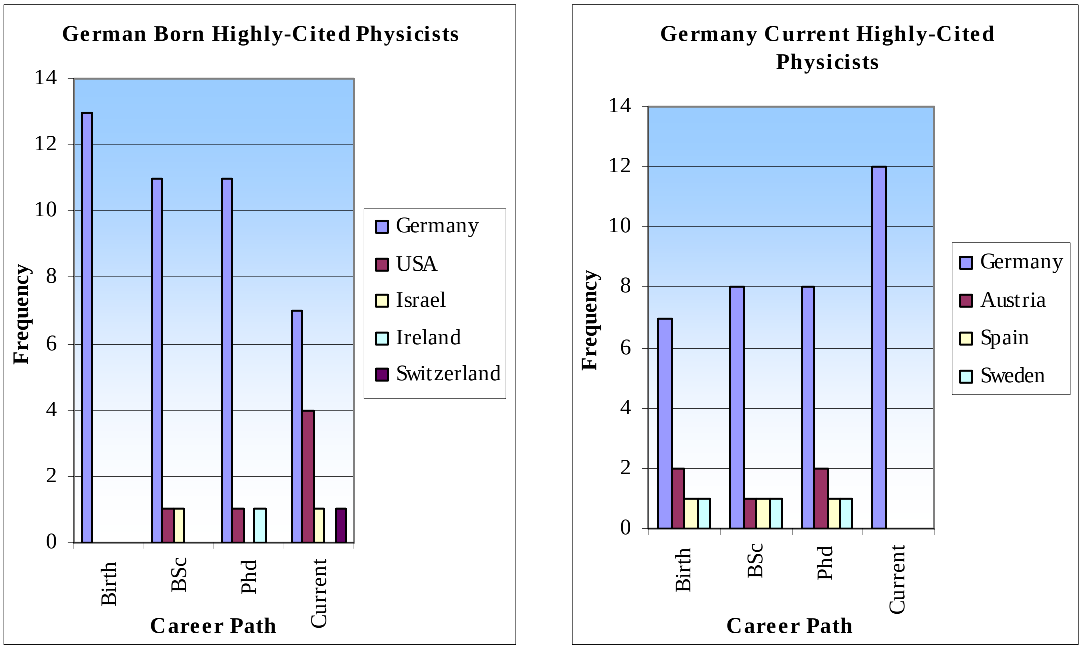


Chart 3b: Highly-cited Physicists: Data on Net Gainers



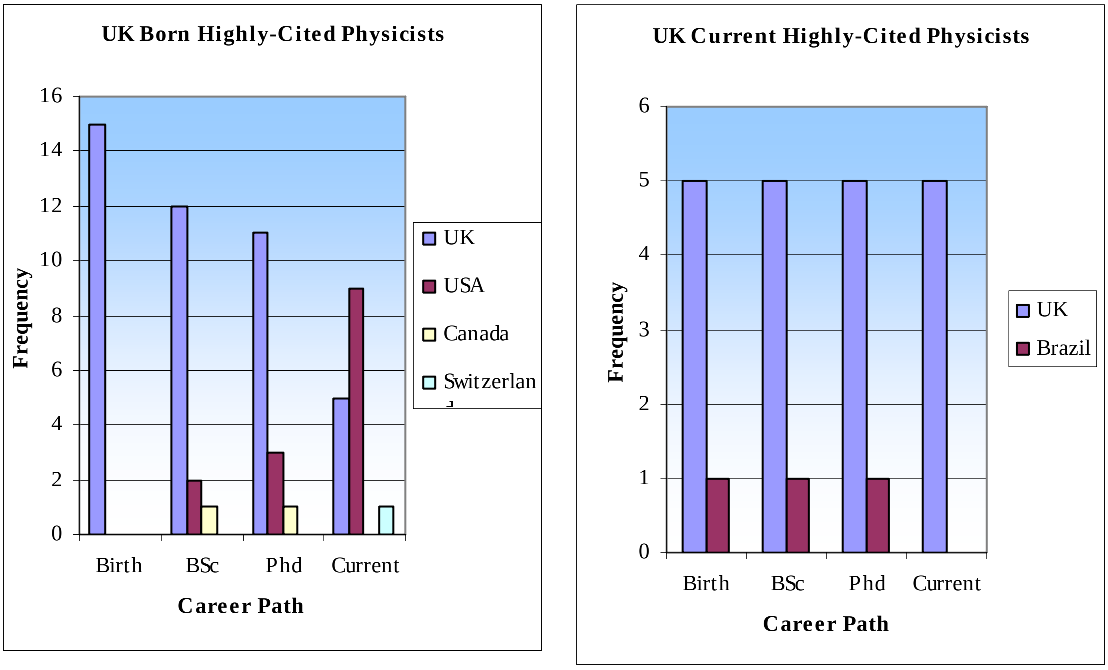
Note: Chart 3b highlights the net gain of physicists within selected countries divided by 10,000 capita.

Chart 4: Insights into Specific Country-Retention: Germany



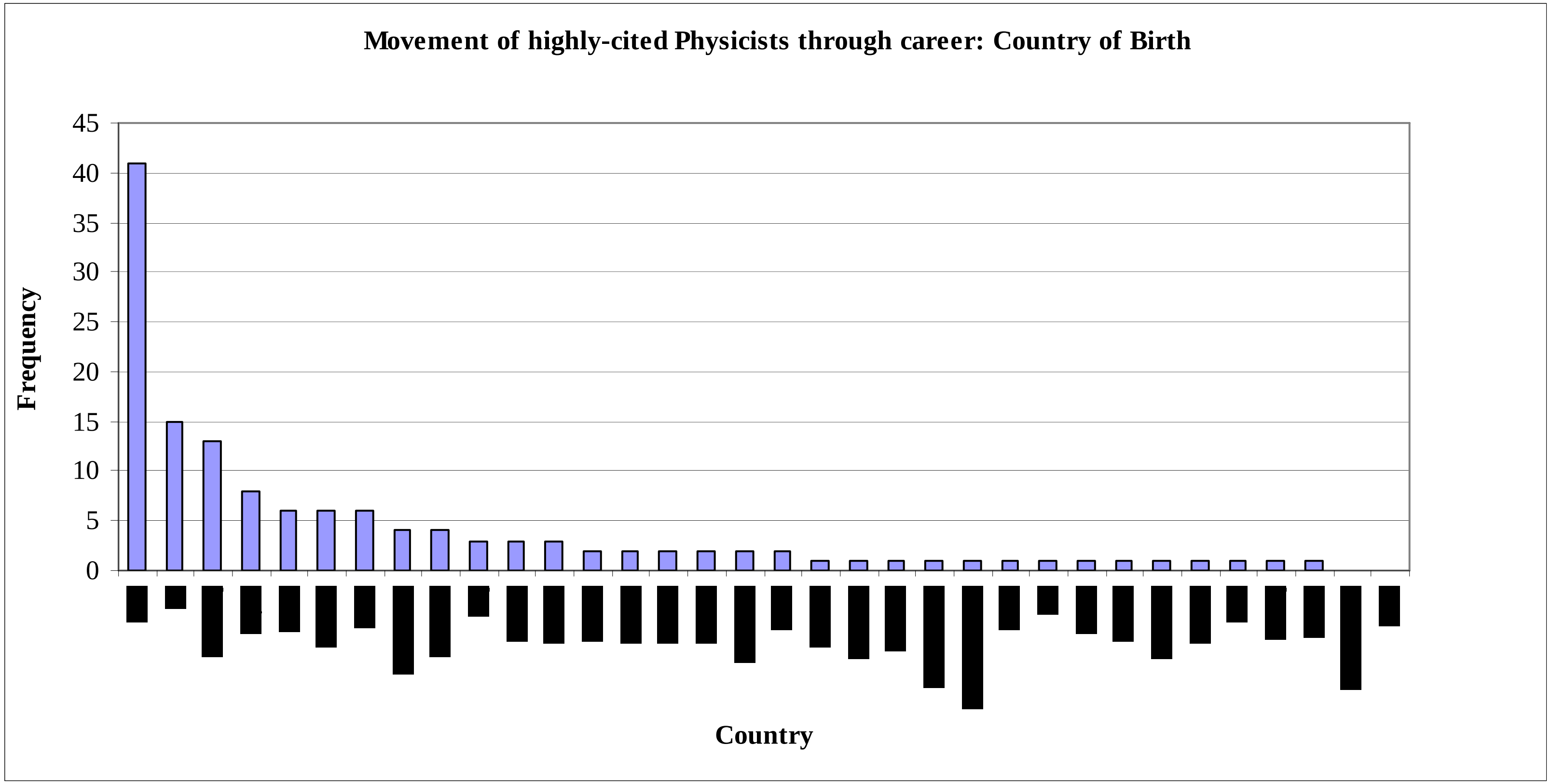
Note: Although German born physicists are drained predominantly to the USA, a larger proportion is retained. Also Germany does gain from other countries and therefore only incurs a slight net drain.

Chart 5: Insights into Specific Country-Retention: UK



Note: UK born physicists are drained predominantly to the USA; a larger proportion is drained than retained. The UK does not significantly gain from other countries.

Chart 6a: Movement of highly-cited physicists through their careers: Country of Birth



Charts 6a and 6b highlight the movement of highly-cited physicists throughout their careers. They illustrate the observation that whilst many countries produce physicists they are funnelled to around half the original number of countries. Although only 30% of highly-cited physicists are born in the USA, 67% are currently located there.

Chart 6b: Movement of highly-cited physicists through careers: their current country of employment

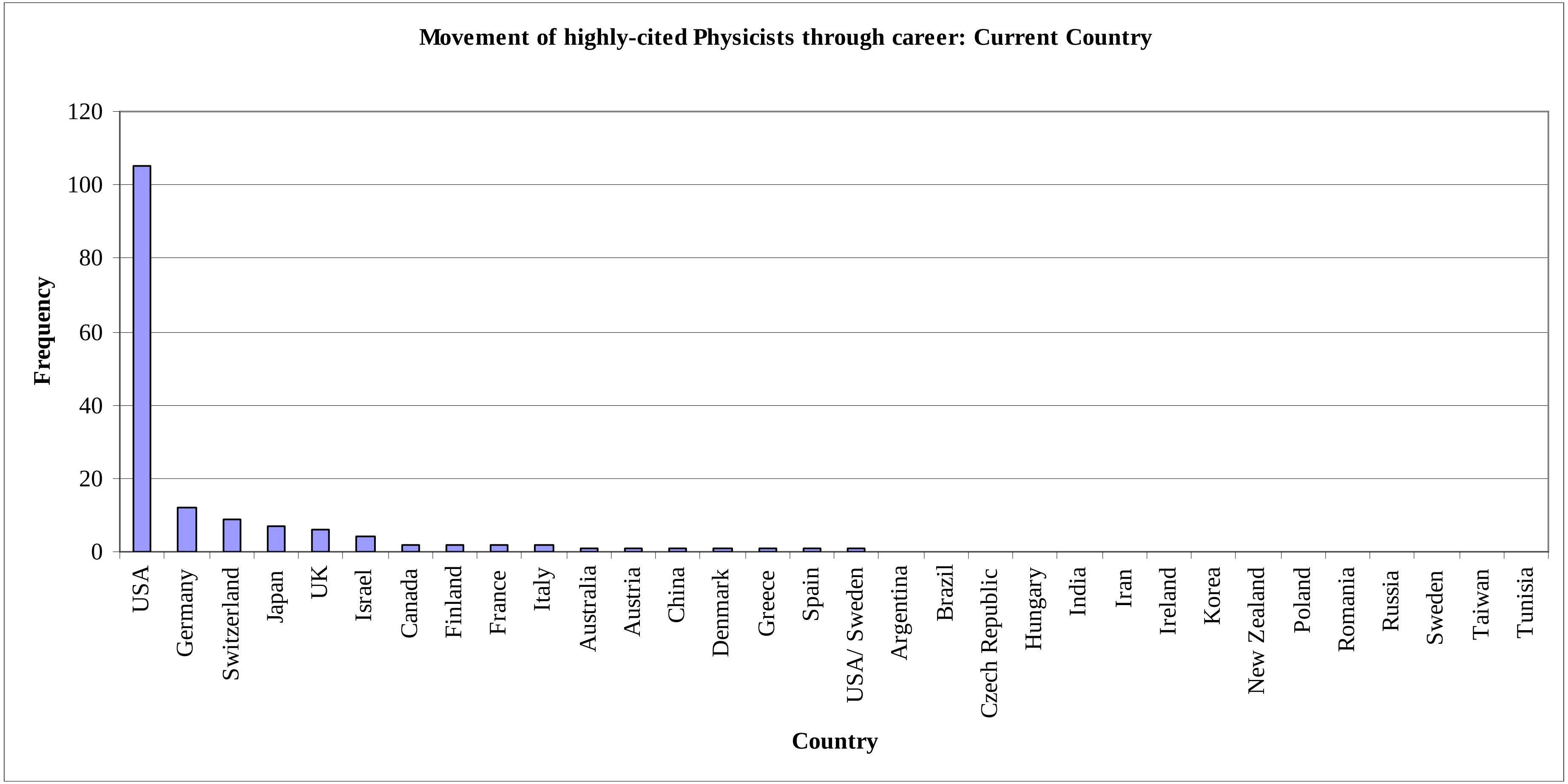


Table 2: Data on Physicists

	Birth (32 countries)	**BSc.** (30 countries)	**PhD** (22 Countries)	**Now** (16 countries)
1st	USA (29.7%)	USA (43.3%)	USA (55.1%)	USA (67.1%)
2nd	UK (10.9%)	Germany (8.7%)	UK (8.9%)	Germany (7.6%)
3rd	Germany (9.4%)	UK (8.0%)	Germany (8.2%)	Switzerland (5.7%)
Others	50%	40%	27.8%	19.6%[11]

Table 3: Highly-cited Physicists – Overall movement

Current location	Frequency	Percent
In country of Birth	77	56.2
Not in country of Birth	60	43.8

Note: This table highlights the overall movement of highly-cited physicists from birth to current location.

11 The UK was ranked 5th with 3.8% of the physicists, after Japan which was 4th with 4.4%.

Table 4: Summary of the Physicists' h-indexes

No. Observations	158
Mean	58.97
Standard Deviation	13.52
Minimum	22
Maximum	115
Median	57

Chart 7: Mean h-index in physics by current country affiliation

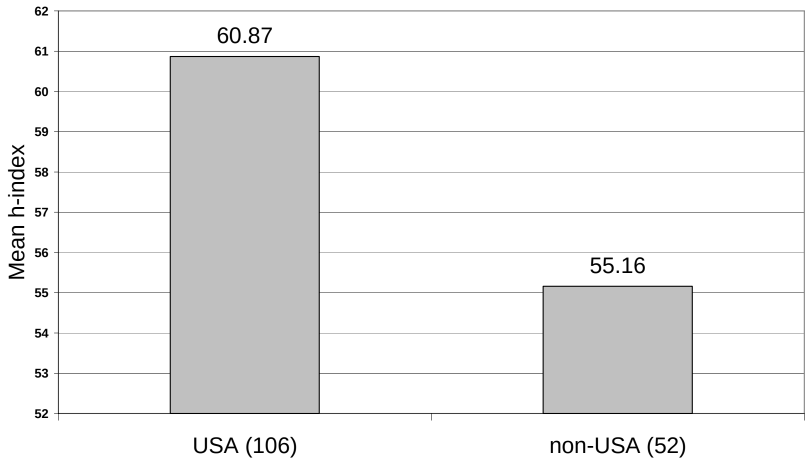


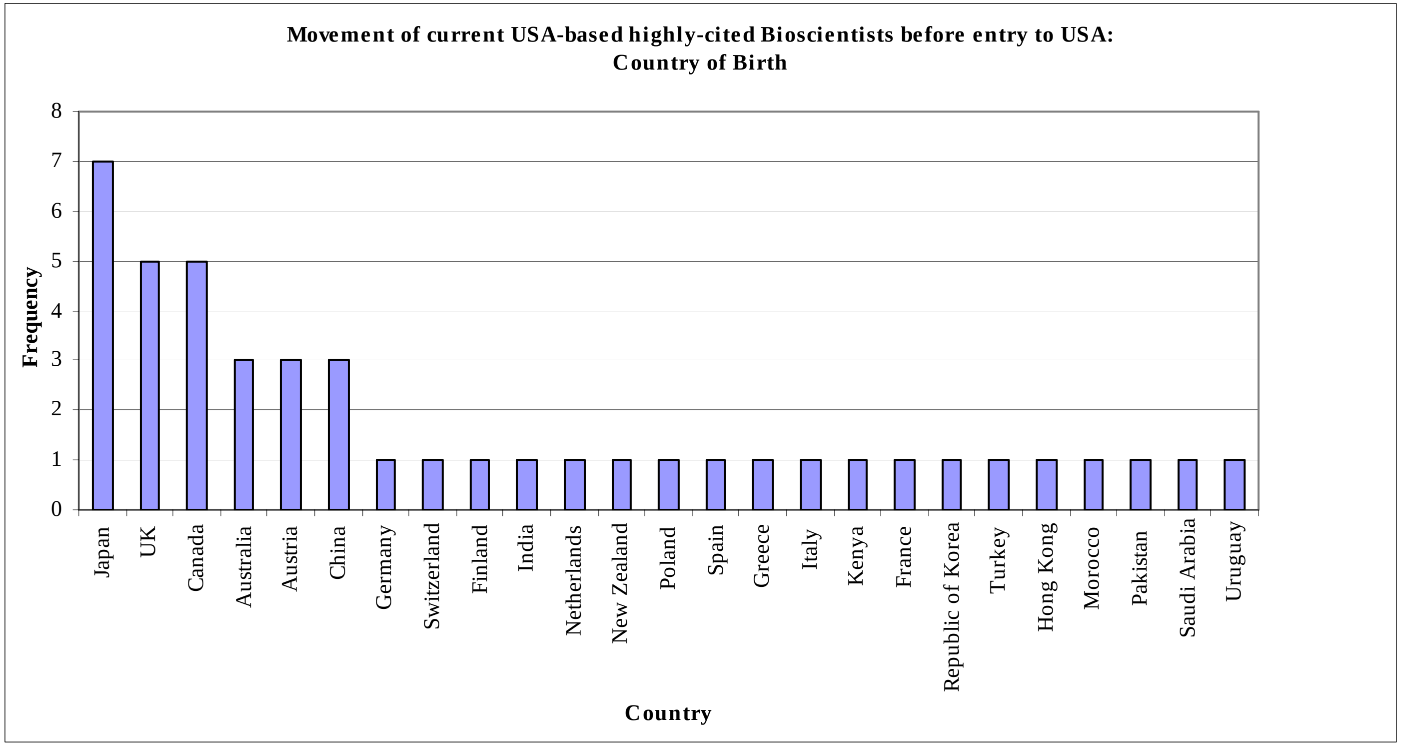
Table 5: Productivity differentials between those who moved and those who did not

Stage	**Average if not moved country since stage**	**Average if moved country since stage**	**Statistically different?**
Birth	60.69	57.66	No, t = -1.24
BSc.	60.04	59.21	No, t = -0.36
PhD.	59.19	58.38	No, t = 0.33

Chart 8a: Movement of Current USA-Based Highly-cited Bio-scientists Before Entry to USA: Country of Birth

Sample Size: 163

Error: Country of birth missing: 50 (30.7%), UG institution missing: 21 (12.9%), PG institution missing: 15 (9.2%)



Note: Charts 8a and 8b highlight the movement of highly-cited Bio-scientists before entry to the USA. They show the funnelling effect towards the USA as well as the UK. All the above Bio-scientists are currently employed in the USA therefore the funnelling continues post-Phd.

Chart 8b: Movement of Current USA-based Highly-cited Bio-scientists Before Entry to USA: Country of PhD

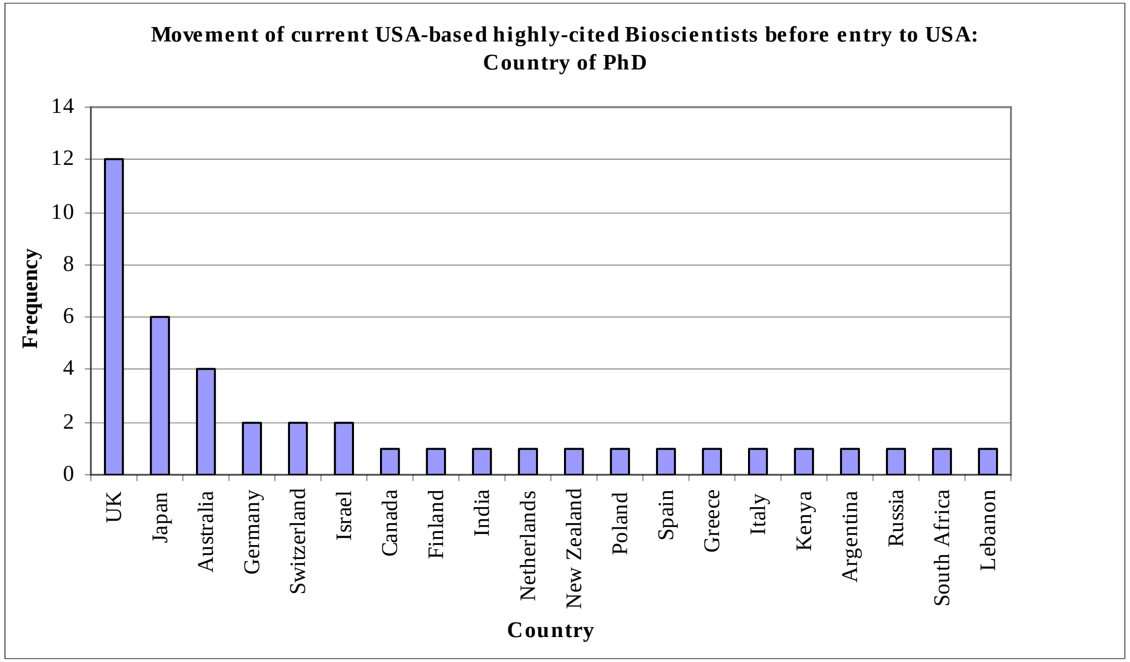
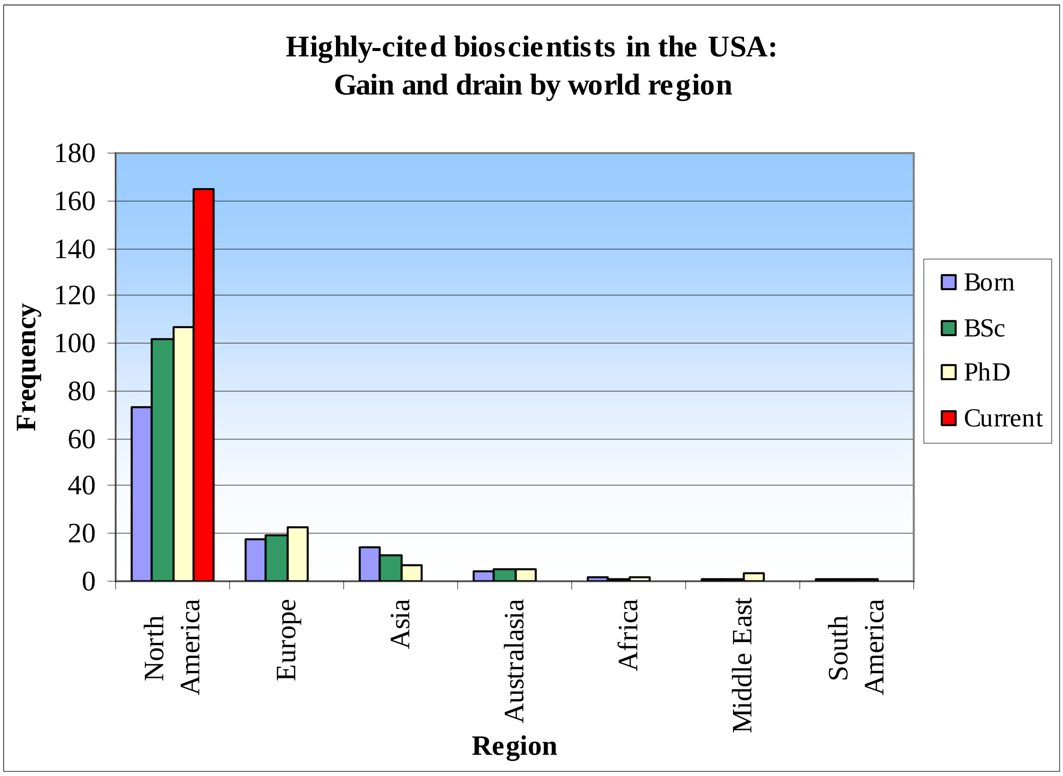


Chart 9: Highly-cited Bio-scientists: Gain and Drain by World Region



Note: All the above Bio-scientists are currently in the USA. This highlights the overall gain of North America and the subsequent drain from all other regions.

Figures for above highly-cited Bio-scientists currently in the USA

Stage	Percent in USA	Percent in Rest of World
Born	60.2	39.8
BSc	69.7	30.3
PhD	71.6	28.4
Current	100	0

Table 6a: Funnelling coefficients for Highly-cited Physicists overall

Sample: 158

Stage	% moving	% remaining	Funnelling Co-efficient
Birth to BSc	15.3	84.7	0.15
BSc to PhD	17.3	82.7	0.17
PhD to Current	24.8	75.2	0.25

Note: The extent of funnelling is determined by the percentage moving to a different country at each stage of their career (Birth, BSc, PhD, Current). The greater the co-efficient the greater the migration. Tables 6a, 6b and 7 highlight this funnelling co-efficient.

Table 6b: Funnelling coefficients for Highly-cited Physicists – Current USA only

Sample: 105

Stage	% moving	% remaining	Funnelling Co-efficient
Birth to BSc	20	80	0.20
BSc to PhD	17.5	82.5	0.18
PhD to Current	100	0	1

Table 7: Funnelling coefficients for Highly-cited Bio-scientists in the USA

Sample: 163

Stage	% moving	% remaining	Funnelling Co-efficient
Birth to BSc	9.3	90.7	0.09
BSc to PhD	11.3	88.7	0.11
PhD to Current	100	0	1

Table 8: Funnelling and the h-index for highly-cited Physicists overall

Sample: 158

Birth to BSc	Mean	Lower bound (95%)	Upper bound (95%)
Moved	61.75	57.08	66.42
Remained	59.17	56.46	61.88
BSc to PhD	**Mean**	**Lower bound (95%)**	**Upper bound (95%)**
Moved	60.08	55.53	64.62
Remained	59.35	56.93	61.77
PhD to Current	**Mean**	**Lower bound (95%)**	**Upper bound (95%)**
Moved	59.08	56.54	61.61
Remained	59.08	55.07	63.08

Note: Tables 8, 9 and 10 show the current h-index for those physicists who remained and those who moved at each stage. To allow some comparison with the USA-only bio-scientist data in table 10, table 9 is constructed using data on physicists currently in the USA. There is no significant difference (at 95% confidence) between movers and stayers within the two data sets.

Table 9: Highly-cited Physicists – Current USA only

Sample: 105

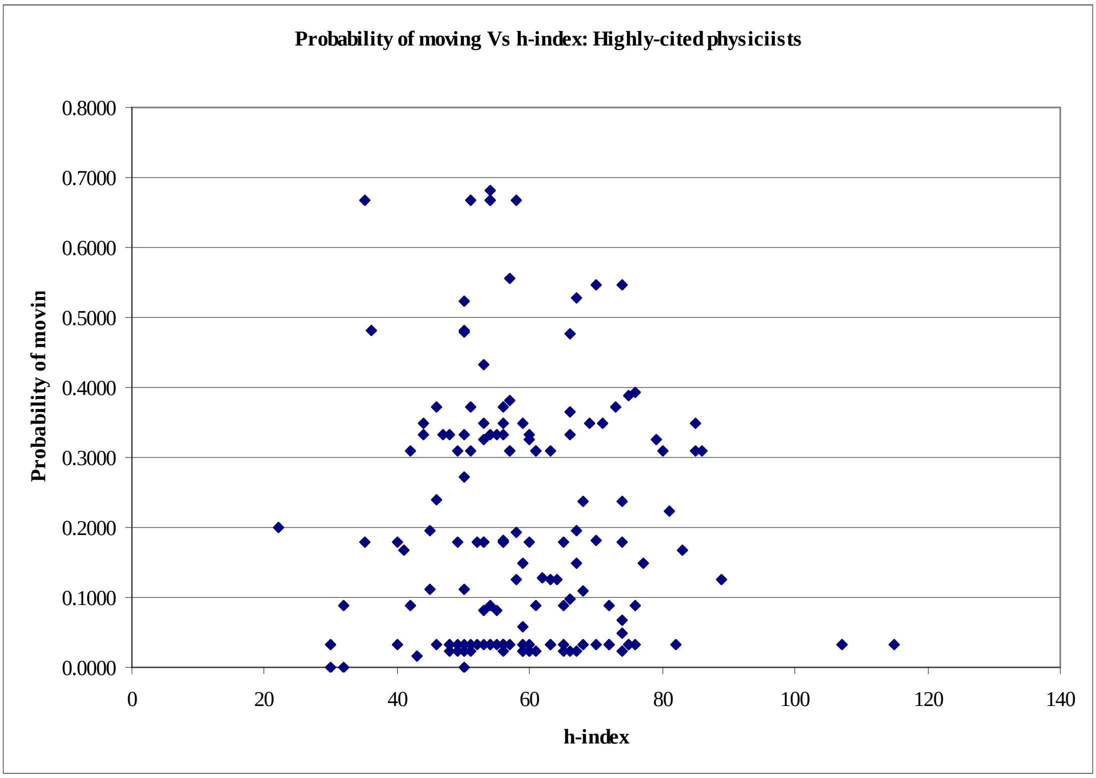
Birth to BSc	Mean	Lower bound (95%)	Upper bound (95%)
Moved	63.82	59.05	68.59
Remained	60.76	57.19	64.34
BSc to PhD	**Mean**	**Lower bound (95%)**	**Upper bound (95%)**
Moved	61.67	55.33	68.00
Remained	60.79	57.94	63.63

Table 10: Highly-cited Bio-scientists in the USA

Sample: 163

Birth to BSc	Mean	Lower bound (95%)	Upper bound (95%)
Moved	88.60	70.51	106.69
Remained	89.67	82.80	96.54
BSc to PhD	**Mean**	**Lower bound (95%)**	**Upper bound (95%)**
Moved	83.38	78.13	88.62
Remained	88.63	82.38	94.87

Chart 10: Probability of Moving Plotted Against their h-index: Highly-cited Physicists



Note: Chart 10 shows h-index against probability of moving. This probability of moving is calculated by country at each career stage for each individual. There is little relationship between the two in terms of highly-cited physicists.

Table 11: The Mean h-index Values for Migrating and Non-migrating Physicists

Country BSc	Country Now	Number	Average h-index
Asia	Asia	10	56.1
Asia	Europe	1	59
Asia	North America	6	55.5
Europe	Europe	31	56.1
Europe	North America	8	63.1
North America	North America	91	61.2
Oceania	Europe	1	57
Oceania	Oceania	1	54
South America	Europe	1	55
South America	North America	2	52

Table 12: Productivity Equations for Highly Cited Physicists

(t-statistics in brackets; estimation is by OLS; bold indicates significant at the 5% level)

Dependent Variable: Natural logarithm of the h index

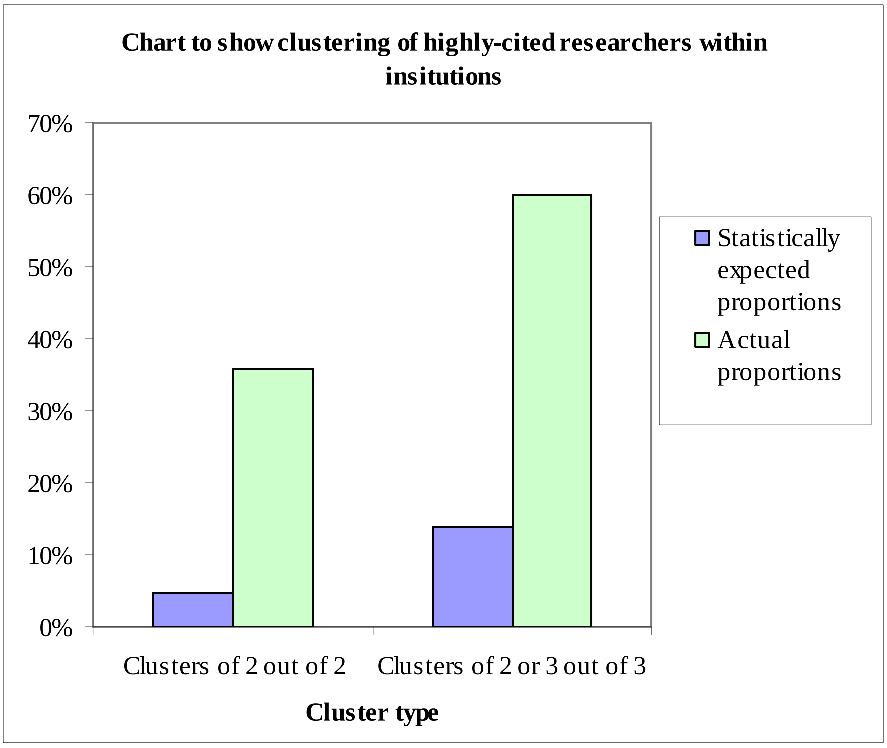
Constant	**3.834 (53.23)**	**3.828 (48.39)**	**3.804 (48.71)**	**3.737 (44.92)**	**3.739 (44.62)**
Years since Phd	**0.006 (3.10)**	**0.006 (2.73)**	**0.006 (2.55)**	**0.007 (2.96)**	**0.007 (2.94)**
USA Born		0.037 (0.83)	-0.049 (-0.88)	-0.063 (-1.14)	-0.071 (-1.10)
USA Phd			**0.131 (2.56)**	0.058 (0.95)	0.051 (0.75)
Now in USA				**0.121 (2.13)**	0.137 (1.59)
BSc outside USA * Now in USA					-0.0186 (-0.25)
R^2	0.0579	0.0605	0.1045	0.1340	0.1344
R^2_{adj}	0.0519	0.0466	0.0844	0.1079	0.1016
Number of observations	158	138	138	138	138

Dependent Variable: Natural logarithm of total citations

Constant	**9.161 (67.83)**	**9.150 (62.40)**	**9.120 (62.17)**	**9.023 (57.33)**	**9.027 (56.95)**
Years since Phd	**0.015 (3.79)**	**0.014 (3.45)**	**0.014 (3.32)**	**0.015 (3.60)**	**0.015 (3.56)**
USA Born		0.073 (0.88)	-0.034 (-0.33)	-0.054 (-0.52)	-0.071 (-0.58)
USA Phd			0.163 (1.70)	0.058 (0.50)	0.044 (0.34)
Now in USA				0.175 (1.63)	0.208 (1.27)
BSc outside USA * Now in USA					-0.038 (-0.27)
R^2	0.0845	0.0906	0.1099	0.1273	0.1278
R^2_{adj}	0.0786	0.0772	0.0900	0.1010	0.0947
Number of observations	158	138	138	138	138

Chart 11: Evidence of High Levels of Clustering within Subjects

Sample = All institutions beginning with "University" or equivalent on www.isihighlycited.com.



Note: This analysis uses www.isihighlycited.com. The first clustered columns represent universities with only two ISI Highly Cited Researchers in the whole university and the second clustered column is universities with only three ISI Highly Cited Researchers in the whole university. In the first case, the two researchers are in the same field for approximately one-third of the time. In the second case, for more than half the time at least two of the three researchers are in the same field. The statistically expected propositions are given on Chart 11 for comparison. Tables 13 and 14 give further insights into the data used in Chart 11.

Table 13: Clusters of 2 out of 2

Summary of findings	Total
Total sample of institutions	430
Institutes with only 2 highly-cited researchers	67
Number of these with 2 highly-cited researchers in same research area	24
Percentage with same areas	35.8%

Table 14: Clusters of 2 or 3 out of 3

Summary of findings	Total
Total sample of institutions	430
Institutes with only 3 highly-cited researchers	30
Number of these with 2 or 3 highly-cited researchers in same research area	18
Percentage with same areas	60.0%

Appendix 1: Nobel Prize Laureates

Table 15a: Among current highly-cited physicists, there are 7 Nobel Laureates in Physics.

name	hindex	results	avcite	totalcite	uniname	born	yborn	bsc	ybsc	phd	yphd	current country	age
Anderson, Philip Warren	75	289	135.45	135831	Princeton University	USA	1923	USA	1943	USA	1949	USA	84
Wilczek, Frank	72	322	66.17	21307	Massachusetts Institute of Technology	USA	1951	USA	1970	USA	1974	USA	56
Tsui, Daniel C.	67	474	31.71	15030	Princeton University	China	1939	USA	1957	USA	1967	USA	68
Gross, David J.	62	127	90.025	20242	University of California, Santa Barbara	USA	1941	Israel	1962	USA	1966	USA	66
Koshiba, Masatoshi	59	579	32.2	18645	University of Tokyo	Japan	1926	Japan	1951	USA	1955	Japan	81
Stormer, Horst L.	56	214	56.23	12034	University of Columbia	Germany	1949	Germany	1972	Germany	1977	USA	58
Binnig, Gerd K.	40	82	159.05	13042	IBM Zurich Research Laboratory	Germany	1947	Germany	1973	Germany	1978	Switzerland	60

Table 15b: Among current highly-cited Bio-scientists in the USA there are currently 8 Nobel Laureates in Medicine.

Name	h-index	D.O.B	Country of birth	UG granting institution	PG degree granting institution	Current Institution
Greengard, Paul	131	12/11/1925	USA	Hamilton College, Clinton, NY, USA	Ph.D The Johns Hopkins University, Baltimore, MD, USA	Rockefeller University
Gilman, Alfred G.	110	07/01/1941	USA	Yale University, New Haven, CT, USA	Ph.D Case Western Reserve University, Cleveland, OH, USA	University of Texas Southwestern Medical Center at Dallas
Krebs, Edwin G.	100	06/06/1918	USA	University of Illinois, USA	Washington University School of Medicine, USA	University of Washington
Cohen, Stanley	-	11/17/1922	USA	Brooklyn College, Brooklyn, NY, USA	Ph.D University of Michigan, East Lansing, MI, USA	University of Arizona
Brown, Michael S.	161	04/13/1941	USA	University of Pennsylvania,PA, USA	M.D. University of Pennsylvania, Philadelphia, PA, USA	University of Texas Southwestern Medical Center at Dallas
Goldstein, Joseph L.	159	04/18/1940	USA	Washington and Lee University, VA, USA	M.D. University of Texas Southwestern Medical Center, USA	University of Texas Southwestern Medical Center at Dallas
Guillemin, Roger C.L.	95	01/11/1924	France	University of Dijon, France	Ph.D University of Montreal, Canada	Salk Institute for Biological Studies
Khorana, H. Gobind	76	01/09/1922	Pakistan	M.Sc. Punjab University, Lahore, Pakistan	Ph.D University of Liverpool, United Kingdom	Massachusetts Institute of Technology

Appendix 2: Qualitative insights from highly-cited physicists: UK leavers

Q. We would like to know if British Physicists who emigrate go on to do significantly better research than if they had remained. This is obviously a difficult question to answer. But what is your opinion, in the case of your own work?

"I left the UK to go to graduate school (at the University of California, Santa Barbara) in 1965. I went with a "green card" (permanent resident visa) with the intention of becoming a US citizen. I had both professional and personal reasons for making this decision. In 1965, the UK was in a downward spiral - the economy was failing because of frequent "wild-cat" strikes by the labor unions, and the rigid class system ***. The American research community was larger, more dynamic and much better supported. As a young scientist with a "working-class" background, I believed at the time, and still do, that my opportunities in the United States were much better than in the UK.*** *After completing graduate school, I joined a large American company that had a strong commitment to basic research, and worked there for 23 years. The UK had few, if any, industrial laboratories of the same quality or size.* ***I do believe that I have been able to do significantly better research in the United Sates than I would have been able to do in the United Kingdom.*** *I also believe that I have done better personally* ***. The level of support (equipment, infrastructure, financial support, etc.) is important, and I believe that this has been a significant factor in my success in the United States. Almost certainly, I would not have received the same level of support had I remained in the UK*** *."*

"This is a very difficult question to answer but, ***in my own case, I think that I probably did carry out better research in the US that I would have been able to do if I had stayed in the UK.*** *However, in my case, I think that working at IBM Research played a very important role in my research since I was better able to understand what's important in taking a fundamental scientific discovery into a useful technology. The importance of much research today is often judged by its potential commercial impact."*

"In my case I was fortunate to come to JILA soon after it was formed. Our AMO physics group, of roughly ten senior scientists, is now rated #1 worldwide (with Nobel prizes in 2000 and 2005 - and more to come!). ***In no way would it have been possible for me to have had***

such outstanding colleagues and facilities in the UK. In fact my atrocious Norfolk accent (I was a country scholarship boy) would probably counted against me in the early 60s."

"In my case, I had access to a much greater range of technology in my field of interest by moving to the US when I did (I moved to Bell Labs). There is no doubt that was helpful to my research. The environment in Bell Labs was also very conducive to doing good research because the work was relatively well supported financially without the continual need for long grant proposals. That particular research model is, however, almost dead. In my current work at a major research university, ***I also benefit from a strong depth of available technology, technology that is available because of the coexistence of top research in both science and engineering at one institution. That combination of the best science and the best engineering is a particular strength of some top institutions in the US, and is much less common in the UK, perhaps because of a lower perceived status of engineering there*****.** ***Another benefit in the US compared to the UK is that there is not just one source for research funding with only one set of values defined by one group of people.*** *None of us is smart enough to know the "right" answer as to what work should be funded, and a diversity of sources helps avoid narrowness of criteria for what is "good"."*

Key themes

- ⇒ Class system in 1960s UK
- ⇒ Realised more of their potential in USA
- ⇒ More funding, facilities and emphasis on research area in USA

Q. And in the case of other scientists of whom you know, would you say that their work was improved by leaving Britain?

"I am not in close contact with many British scientists (either those working in Europe or those working in the USA). However, ***my overall impression is that scientists from the UK who are now working in the US have done better work than their colleagues who remained in the UK. I also believe that scientists born in the UK who are now working in the USA have done better work, an average, than their American born colleagues. The United States has also provided scientists born abroad with the opportunity to become leaders in the research community and research institutions.*** *I am not personally familiar with British scientists who have come to the US in mid-career, and for this reason, it is difficulty to judge whether leaving Britain for the USA has improved the work of the scientists who I know personally.* ***I believe that scientists who come to America from abroad are, on average, more ambitious, energetic and competitive than their colleagues who remain behind. For this reason, it is difficult to assess whether they have done better because of the advantages that America offers or because they are not representative of the research community that they have come from****."*

"Looking at my peers from my Cambridge and London, it is clear that those who came overseas had more opportunities and were much more likely to be successful scientists than those that stayed in the system. ***Indeed, many of the "top" scientists in the UK today have spent much of their early careers in the US."***

"There is one other benefit of leaving Britain, which has nothing to do with the US being better than the UK; it is simply that it is more stimulating to move. The best end result here is not to want to stop people leaving Britain, but to have a healthy and balanced continual exchange of people.*"*

Key themes

- ⇒ Others have realised more of their potential in USA
- ⇒ Cause and effect difficult to separate: do better academics go to the USA or do they become better because they go to the USA?
- ⇒ The issue is not brain drain so long as there is brain circulation