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ABSTRACT

The Elite Brain Drain*

We collect data on the movement and productivity of elite scientists. Their mobility is remarkable: nearly half of the world's most-cited physicists work outside their country of birth. We show they migrate systematically towards nations with large R&D spending. Our study cannot adjudicate on whether migration improves scientists' productivity, but we find that movers and stayers have identical h-index citations scores. Immigrants in the UK and US now win Nobel Prizes proportionately less often than earlier. US residents' h-indexes are relatively high. We describe a framework where a key role is played by low mobility costs in the modern world.

JEL Classification: O3, J6

Keywords: mobility, science, brain drain, citations

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The Elite Brain Drain

Where scientific enquiry is stunted, the intellectual life of a nation dries up, which means the withering of many possibilities of future development... Einstein (1934, p.30)

1. Introduction

This study is an analysis of the international movement and productivity levels of elite research scientists. We begin with data on Nobel Prizes. We then construct a data set on the world's most highly-cited physicists. Although our sample, of 158 people, is inevitably a small one, the individuals covered within it seem of particular interest. The paper discusses the conceptual implications of the observed empirical patterns.

We attempt to address questions such as the following [and give brief answers in parentheses]:

- How mobile are the world's top research scientists, and do they migrate disproportionately to the richest countries? [Very; yes]
- Are elite movers more productive, on average, than elite stayers? [No]
- How -- in the spirit of Freeman (2006) -- might the new world of globalization be expected to influence nations' across-person productivity distributions? [To make them more similar]
- Are physicists who migrate to the United States more productive than home-grown US physicists? [No]

While there is a large literature on the brain drain[1], few researchers have looked at migration among world-class scientists.

To anticipate results to come, it is shown that nearly half of the elite physicists in our sample no longer work in the country in which they were born, that the major per-capita importers are the US and Switzerland, and that (at least within this sample of unusually highly-cited people) migrants and non-migrants have similar productivities as measured by citations h-indexes. Those in the sample who move from Europe to the US go on to be neither more nor less distinguished than American-

[1] Space constraints mean that it is not possible to summarize the literature here, but valuable papers in economics include Beine, Docquier and Rapoport (2001, 2008), Bhagwati and Hamada (1974), Johnson and Regets (1998), Kanbur and Rapoport (2005), Saint-Paul (2004), Schiff (2005), and Grossman and Stadelmann (2008). Like us, Stephan and Levin (2001) and Constant and D'Agosto (2008) focus on truly high-skill individuals. Commander et al (2004) is a helpful survey, and Zimmermann (1995) and Stephan (1996) review parts of this literature. See also Bekhradnia and Sastry (2005), Kuhn and McAusland (2006), and Zaiceva and Zimmerman (2008).

born elite physicists. One way to make sense of all these patterns, we argue, drawing partly upon a simple formal model, is that in a world with low mobility costs the distribution of talent can be expected to be similar across different countries.

More broadly, this paper relates to policy issues discussed in, for example, a recent 2007 editorial in Nature, and a literature on the competitiveness of European and US economics and science (Levin and Stephan 1999; Machin and Oswald 2000; Regets 2001; Royal Society 1963; Oswald 2007b, 2009; Summers 2007; UUK 2007). Those persuaded by a sanguine view of international brain 'circulation', rather than drain, may wish to know that our later data paint largely a one-way picture, and one disproportionately towards the United States.

2. Theoretical Issues

Consider a world in which scientists vary in their innate ability and productivity. Let a person's productivity be q, which for simplicity here is defined to lie between 0 and 1. We can think of Nobel Prize winners, say, as having a level of q that is close to the upper bound of unity.

Assume the talent distribution is described by a density function f(q). Among 'elite' scientists, define a cut-off minimum threshold of quality, given by q*. Assume that such scientists can choose whether or not to move to a new country. This receiving country is rich, by assumption, and will pay a percentage wage premium, p, compared to the home country.

There is a cost of movement, c. The model will be a timeless one, but this cost could be thought of as a continuing one per-unit-of-time. It might, for instance, be viewed as, in part, capturing any continuing cultural and personal cost caused by living outside one's nation of birth.

The net utility levels of individuals are taken to be given by a simple additive form:

Utility of a mover $= (1+p)q - c$ (1)

Utility of a stayer $= q$ (2)

so that an individual will therefore choose to move if

$(1+p)q - c - q = pq - c > 0.$ (3)

The productivities, on average, of the movers and stayers can then be calculated. The average productivity of elite migrants is

$$M = \int_{c/p}^{1} qf(q)dq \Big/ \int_{c/p}^{1} f(q)dq \qquad (4)$$

By contrast, the average productivity of stayers (in the country to which the migrants are moving), who are drawn partially from a different segment of the talent distribution, is

$$S = \int_{q^*}^{1} qf(q)dq \Big/ \int_{q^*}^{1} f(q)dq \qquad (5)$$

The difference in mean productivities is therefore

$$D = D(c, p, q^*) = M - S \qquad (6)$$

and it can be checked that D(c, p, q*) is an increasing function of the mobility cost c, and equivalently a decreasing function of the premium p, so that for example:

$$\frac{\partial D}{\partial c} = -\frac{c}{p} + \int_{c/p}^{1} qf(q)dq \Big/ \int_{c/p}^{1} f(q)dq = M - \frac{c}{p} \geq 0 \qquad (7)$$

If the cost of mobility and the premium are both positive, then in a large class of cases:

$D(c, p, q^*) > 0$ (8)

and the quality of movers, on average, will exceed the quality of stayers. This is because the return from moving is biggest for the most able people.

Put into words, if it is extremely costly to leave one's country, only absolutely outstanding scientists will find it worth their while. Such people will then stand out in ability among those of their adopted nation. When the costs of international mobility are sufficiently low, however, elite migrants and elite non-migrants come from approximately the same section of the underlying talent distribution, and they will therefore have similar observed productivity levels. In this case, as c declines, the difference D approaches zero.

Kwok and Leland (1982) also allow for distributions of ability in the two countries; but they assume the existence of asymmetric information, and conclude that in equilibrium the average productivity of movers will always exceed that of those workers who stay. We later try to check that empirically. New work on the theory of the brain drain, and how an optimizing government should act, includes Egger et al (2007) and Ionescu and Polgreen (2009).

3. Earlier Evidence

Levin and Stephan (1991) gathered data on the age and publishing productivity of PhD scientists in American institutions. The authors examined six scientific specialities.[2,3] They used four different measures for productivity[4] and found that in five out of the six specialities -- particle physics being the exception -- an increase in age significantly reduced the level of productivity when controlling for ability and motivation etc. Weinberg and Galenson (2005) analysed the optimal productivity age of Nobel Prize winning economists. They concluded that experimental and applied economists peaked later in life, possibly due to accrued knowledge over time. In contrast, theoretical economists did their best work early. Carayol and Matt (2005) combined both individual and collective factors to analyse influences on productivity. They studied more than a thousand faculty members at Louis Pasteur University. Dietz and Bozeman (2005) looked at scientists' inter-sector job movements within the US. They surveyed 1,200 scientists, from various fields, with 5,490 career moves between them. The authors showed that job transfers were

[2] Three in physics (solid state/condensed matter physics, particle physics, and atomic and molecular physics) and three in Earth Science (oceanography, geophysics, and geology).

[3] Defined by Laudel (2003, p.218) as "a community of scientists who directly or indirectly interact in the production of new knowledge about a common subject matter".

[4] Publication counts over two years; these publication counts adjust for co-authorship, and then adjust for journal impact factors (a measure of quality) and are finally adjusted for both co-authorship and journal impact factors.

associated with higher productivity. However, they could not prove a causal relationship. Laudel (2003) used bibliometric methods (analysing patterns in publications) to investigate the movement of elite scientists. Laudel (2005) extended her previous paper, examining the brain drain of elite scientists. She studied two different specialities, angiotensin and vibrational spectroscopy, and generated three important conclusions. First, micro-level studies may identify brain drain effects which macro studies do not, because migration flows can counteract each other. Second, some specialities have much higher levels of migration than others. Finally, migration generally occurs young, and before scientists have gained 'elite' status.

In the work closest to our own, Ioannidis (2004) took a cross-section of 1,523 scientists, including 46 physicists, from the Institute of Scientific Information's (ISI) Highly Cited Researcher scientist lists. Although the database had many missing observations (because of non-completion by the majority of individuals), the author was able to analyse the patterns in scientists' countries of birth and their current country affiliations. There was great variation across scientific fields. On an aggregate level he found that approximately one third had migrated, and that three-quarters of this third had migrated to the US. Ioannidis argues that although migration may be good for science, because it exposes scientists to new ways of thinking, when one country experiences the majority of the net in-flows the other countries experience a damaging brain drain. He argues that for most fields, excluding those with highly specialised expensive equipment such as nuclear physics, keeping a small network of scientists, a critical mass, in a country is important if the field is not to stagnate.

The previous literature identifies factors correlated with scientists' productivity. Our paper is a (retrospective) study of scientists' mobility. It is difficult to say what in the counter-factual case would have happened to the productivity of each physicist who migrated/remained. Hence this paper cannot conclusively address the question: how does migration affect a person's productivity? Nor can we measure directly how scientists create externalities upon colleagues, although common sense and sources such as Laband and Tollison (2003) suggest they will. Yet Waldinger (2008), using a natural experiment, finds spillover effects only on to coauthors rather than mere departmental colleagues.

This paper provides new data and inquires into the nature of the productivity distribution -- across different scientists within a nation -- that we would expect to see under alternative assumptions.

4. Data on US and UK Winners of Nobel Prizes

There is an anecdotal view that in the modern world the Unites States acts as a giant funnel of scientific talent. We document facts consistent with that claim.

We begin by recording the extent of the decline in the ratio of UK/US Nobel Prizes in science. The results are presented in Table 1. By using biographies and autobiographies on the official Nobel Prize web pages (http://nobelprize.org/nobel_prizes/lists/all), we initially examined data since World War II on all Nobel prize-winners in science broadly defined (physics, chemistry, physiology/ medicine; and economics since 1969). To do so, we treated the national affiliation of each laureate in the same way as the Nobel committee – which assigns the working address of the laureate at the time the prize is awarded. However, official biographies are of varying clarity and completeness, and sometimes it was not possible to be sure of a laureate's educational experience, or to allocate the national provenance of a prize (for example, when the laureate was retired at the time of award, worked in several countries or worked at an international laboratory such as CERN). Such laureates are omitted from the tabulation. As a referee has pointed out, our approach assumes that the selection criterion for winning Nobels has remained the same through time.

Table 1 shows the proportions of US relative to UK laureates for each of three 20-year segments. The data are for the period 1947-2006. For the first third of the period, 1947-66, the UK was a successful Nobel prize-winning nation. It gained nearly half the number of prizes of the US. Over the past 60 years the population of the US has approximately doubled from 150 million to 300 million while the UK population has only increased about 20 percent from 50 million to 60 million. But UK success in winning Nobel science prizes has sharply declined both in relative US: UK terms over the whole period and in absolute numbers of UK laureates over the past 20 years.

A much fuller analysis of UK is provided in the new work of Weinberg (2009).

It may be assumed that a dominant scientific nation will attract high-quality scientists from other countries. This can be studied for the US and UK by looking at scientists who did their university education elsewhere, then migrated either to the US or UK, where they eventually received a Nobel prize. The row in Table 1 ‘Immigrant after first degree’ gives the number of US or UK laureates who moved to the US or UK after they did their first college degree or equivalent; while the row ‘Immigrated after doctorate’ shows the US or UK laureates who had come to the country, where they later won the Nobel prize after completing their doctorate (PhD or an equivalent such as a medical degree). ‘Proportion of immigrant laureates’ is the total immigrant laureates (both after college and doctorate) expressed as a percentage of the total number of laureates. The proportion of immigrant laureates represents an approximate measure of a country’s power to attract the best (potential Nobel-prize-winning) scientists.

These data reveal that in the past 20 years the UK has lost its previous ability to attract future Nobel-prize-winning scientists from elsewhere. There is also evidence of a decline in the percentage of immigrant laureates in the USA: immigrants are now only 19 percent of total laureates. Considering the overwhelming dominance of the US in winning Nobel prizes during 1987-2006, the number of immigrant laureates might have been expected to increase. That this has not happened may indicate signs of increasing parochialism in US science, or perhaps increasing bureaucratic barriers preventing the easy movement of top class scientists into the US. It should be said, however, that the lags between doing the work and receiving the prize make it difficult to say.

Table 1’s row ‘UK to US migration’ shows the number of scientists during a 20-year segment who were educated in the UK but then migrated to the USA and eventually were awarded a Nobel prize. (The reverse situation did not happen during the past 60 years – i.e. by the above definitions there were no UK laureates who had migrated from the USA). This number may be an approximate measure of the greater attractiveness of the US compared to the UK as a place of residence and work for the highest quality scientists. This suggests that the US has become more attractive to UK-educated scientists over the past 60 years. In 1987-2006, for example, five out of fourteen of all UK-educated laureates had moved to the USA by the time they won the Nobel prize.

5. Data on Highly-Cited Physicists

We now draw upon data on elite physics researchers.

In our analysis, the numbers of physicists in each country at first degree and the number currently affiliated are measured, and the net gain for each country can then be established. This is then normalised for population size (source: OECD Statistics). Country of first degree is used rather than country of birth. Each country's net gain is then compared to measures of its wealth to assess if there is a correlation.

There are several ways to calculate a scientist's career productivity. They include the total number of publications, average citations per paper, and total citations. This paper uses a particular citations measure, the h-index. The h-index was proposed by Hirsch (2005), who is a physicist by profession, as an attempt to "quantify the cumulative impact and relevance" of an individual's scientific research output (Hirsch 2005, p.16,568). The measure incorporates a flavour of both quality and quantity of publications. Inevitably, the use of a single measure has disadvantages as well as advantages (Henrekson and Waldenstrom, 2007).

By definition, an h-index of x means that a scientist has x number of papers with x or more citations. This is calculated by ranking a physicist's papers from the most-cited to the least-cited and then descending down the list until the rank of a paper becomes greater than or equal to the number of citations to that paper. The rank of this marginal paper is the h-index.

Like other measures of productivity, the h-index has drawbacks. First, it is affected by career length. Second, although a high h-index typically signifies a high-quality scientist, the reverse is not always true (Hirsch 2005, p.16,571); a scientist with only a few highly cited papers may have a fairly low h-index no matter how important the papers. Third, citations may always not capture a physicist's true impact if there is a bias towards English-language journals (Van Leeuwen et. al. 2001). The h-index also does not account for the number of co-authors on each paper. Hirsch (2005, p.16,574) suggests a normalization of the h-index for the number of co-authors; however, as discussed by Laudel (2003, p.221), there is no easy way of establishing the relative levels of contribution for each co-author. Normalization would underestimate the output of those who gave a high proportion of the input but with a large number of co-authors and vice versa. Accordingly, the h-index here is not adjusted.

6. The Sample of Physicists

Our main sample is drawn from www.isihighlycited.com. We take the ISI list of physicists, which contained at the time of data collection the names of the 272 most-cited scientists writing in physics journals between 1981 and 1999. Laudel (2003, p.219) argues that the ISI's subject groupings are not sufficiently broken down into specialities, and therefore that in-depth analysis of 'cause and consequences' of migration cannot be analysed. However, data on these factors, such as R&D funding, do not have sufficient coverage over physics, let alone its specialities, for that depth of analysis to be undertaken.

The data-collection process took some time. We searched for biographical and bibliometric information on each of the 272 listed highly-cited physicists. We particularly wished to determine career movements and overall career productivity. For each person, their year and place of birth, of first degree, and of PhD, were recorded. So was country of current affiliation. Data were initially gathered from the ISI website and then from physicists' own web-pages. This was followed by a further search of the internet. To gather further information beyond what was available through the web, emails were sent to 146 physicists where their email addresses could be identified. Of these, 63 replied.

In this way, we eventually compiled a data set on 158 highly-cited physicists. However, we obtained data on their first degrees for only 150 of them. Other aggregate data, on countries of origin and of current affiliation, were collected from OECD Statistics. The data for variables such as GDP were averaged between 1970 and 2006 to cover the main period during which the physicists were active. Data were available for 21 countries[5]. In order to maintain consistency, data for the missing countries[6] were not collected from other sources

Our physicists currently live in 16 different countries. This produced some language difficulties for us. We could read websites well only in English or Italian. We used some online translators. Emails were sent in English. To examine a possible bias towards English speaking countries, the proportions of the final 158 physicists can be compared to those of the original 272. The extent of bias seems small. The

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

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

USA, however, appears to be overrepresented, and Japan to be underrepresented. There is no clear way to solve this problem -- our response rate (43%) is similar to those of previous studies (Laudel 2003, p.224) -- although it is considered later.

The next issue was how to calculate productivity levels. We decided to focus on citations rather than numbers of publications[7]. The ISI Web of Knowledge was used to calculate the h-index. This required us to identify each physicist's publication list, which can be problematic when some physicists have the same surname. We decided to consider each individual separately. In many cases, initial inspection showed no problems; physicists had identified how many papers they had published. However, sometimes further examination of the names used on published papers and the institutions worked for had to be undertaken. In two cases, we had such difficulties distinguishing names that the physicists had to be removed from the sample. One advantage of working with the h-index is that the probability of a second physicist with the same surname and initials appearing within the relatively small selection of papers which affect an h-index score is lower than occurs when using data on an entire list of publications. Of the sample of 158 physicists, 1 is female, and 8 have won Nobel prizes. A referee has pointed out that 8 seems a small number given this distinguished group, but presumably some of these scientists will win the prize in the future. The majority, 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 their PhD; 54% have experienced another type of public institution; and 47% have spent a period in the private sector. The mean number of institutions worked in is 6.03. The mean number of countries worked in is 2.41.

7. Migration and Productivity

These physicists were born in 32 different countries. They studied for their first degree in 30 different countries; they did PhDs in 22 countries; and they are presently located in only 16 countries. Hence the data show a kind of 'funnelling' effect of

[7] We had to distinguish between good scientists and outstanding ones. Citations, although not perfect, therefore seemed the best metric. As pointed out by Starbuck (2005), Oswald (2007a) and others, even prestigious journals publish large numbers of papers that make little impact. See Van Raan (2000) for more on the use of citations.

approximately 50% from birth: people from 32 nations now reside in half that number.

The percentage of physicists present in each country shows a gradual funnelling effect towards the USA (Table 2 and Figure 1). At birth, 29.7% of physicists are in the USA. This increases to 43.4% at first degree, to 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 through time in the rest of the world falling dramatically from 56.4% at birth to only 19.6% presently.

Overall, 44% of scientists have moved since birth, 33% since their first degree, and 27% since their PhD. These proportions are in fact only a little different from those of Ioannidis (2004) who, on a much smaller sample, found 50% of physicists had moved since birth. We have data on 158 physicists compared to 46 in Ioannidis's work.

The summary statistics for the individuals' h-index scores can be seen in Table 3. The mean h-index over the sample is 58.97. The minimum and maximum values are 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 were examined. The average number of co-authors for each of the ten varies enormously and the number of affiliated countries from 1 to 7.25. Although there is a tendency for those with more co-authors to have higher h-indexes, the evidence is not substantial. This gives us some reassurance in the decision to not try to adjust h-indexes for co-authorship.

For our sample, we compared these h-index results with the physicists' total number of published papers, total citations, and average citation count per-paper. For the h-index, there is no correlation with the last of these, average citations per article. But there is a significant positive correlation of 0.40 with total number of published papers, and of 0.54 with total citations. People with a high h-index also score highly on these two criteria.

Figure 2 shows that those currently in the USA have an h-index which is on average 5.71 higher than those in non-USA institutions. This difference -- one that continues to hold weakly when we adjust the data using regression equations -- is close to statistically significant at the 5% level. There are several possible reasons for this, which we discuss later in the paper.

We now separate the sample into those who have migrated and those who have not. Whether we work with the periods since birth, BSc. or PhD, we find no statistically significant difference in productivity as measured by an h-index (Table 4). There is no way of measuring the productivity levels in the alternative situation. However, Figure 2 suggests that there are country-specific effects.

A natural question for economists is how effectively the rich countries draw in others' top scientists. Figure 3 demonstrates this for Switzerland and the USA. Figure 4 reveals a relationship between the net gain in physicists and the R&D adjusted GDP per capita. The correlation coefficient is then 0.49, significant at the 5% level. Physicists migrate toward richer countries, although the definition of rich should be adjusted to mean rich in R&D funding. Data on the level of physics funding would be still better, but we found it too hard to obtain data consistently across nations.

Figures 5a and 5b depict the productivity levels between continental[8] migratory groups, looking at differences between country of first degree and present affiliation. Table 5 gives fuller data. Those individuals who emigrated from Europe to North America emerge as the most productive with an average h-index of 63.1. Those who remained in North America are the second most productive group: their h-index is 61.2. The final three major groups -- those who remained in Europe, remained in Asia, and moved from Asia to North America -- have average h-index scores of 56.1, 56.1 and 55.5, respectively. The only statistical significance at the 5% level here is between those who remained in North America and remained in Europe.

There are other migratory groups, within the sample, with only a couple of representatives. This means that meaningful averages could not be constructed.

It seems interesting to note that no physicist left North America nor remained in South America. The European physicists who moved to North America have productivity levels more in line with those of the natives than those left in Europe. The two Asian values are statistically the same.

Some caution should be shown when looking at these results. First, the sub-samples are small, especially for movers. Only 8 Europeans migrated to North America while 91 remained in North America.

To this point, we have shown only raw patterns in the data. We now turn, in Table 6, to regression equations. The dependent variable here is at first, in the upper

[8] United Nation's Statistics Division country classification; Russia is included in Europe, and Turkey in Asia.

part of the table, the logarithm of the scientists' h-indexes. In the lower half of the table, it is the log of total citations to their work.

Going from left to right, the columns of Table 6 gradually build up from a simple to a fuller regression specification. Older people tend to be more cited; this is to be expected merely because career length affects the period over which citations can be accrued. Having ten additional years after the year of the PhD increases a physicist's h-index by 6%. Being born in the United States has a statistically insignificant effect. Residing in the US, however, does have a positive coefficient; it is associated[9] with an h-index approximately 13% higher. Nevertheless, this effect loses statistical significance by the final column of Table 6. In these regression equations, the adjusted R-squared values are fairly low.

Table 6 includes a simple direct test for an interaction effect. Are those who were educated initially outside the United States, but now reside in the USA, more productive (in the sense of having higher h-index scores)? No, not than Americans. In the final column of Table 6, it can be seen that the coefficient on the variable 'BSc outside the US* Now in USA' is approximately -0.02 with a t-statistic of -0.25. Hence it is essentially zero. Migrant elite physicists into the United States do not have an h-index that differs, ceteris paribus, from the h-index of home-grown elite physicists.

The tenor of these conclusions is replicated for the lower panel, using instead Log of Total Citations as the dependent variable, in Table 6.

Table 7, following a referee's suggestion, does a further check. It breaks the data down by the time point of migration to the United States. Interestingly, whatever the stage at which someone migrated, their h index is approximately the same as that of those physicists born in the US. The null of equality of the various key coefficients, as in column 1 of Table 7, cannot be rejected at conventional significance levels. Here the size of effect in the h-index regression equation is fractionally larger than in Table 6's estimates; it varies from 14% to 19%.

The results provide a little evidence that some groups are more productive than others, and in particular that everyone working in the United States tends to have a higher h citations score. However, the reasons for this are more ambiguous. As previously mentioned, there is no clear causal relationship between migration and

[9] The exact effects are calculated from: $100(\exp(\beta)-1)$.

productivity. Put into context, migrating to the USA may make you more productive (direction one) but also the most productive people may be those who are offered jobs in the USA (direction two). Another, and a more sociological, possibility is that those in the American scientific circuit simply cite each other 13%-19% more. All three arguments are plausible, perhaps jointly play some role, and have implications for discussions on the brain drain. Yet with these data it is not possible to distinguish among them.

If direction one is the overriding influence then the world body of scientific knowledge gains from the migration because of the increase in productivity. However, there are further implications for the country left if the field stagnates or disappears. If direction two is the overriding influence, then the USA is taking the best physicists, although it already had a large portion of them. It is the success of this home-grown group of US physicists that suggests it is the resources in the USA that make their physicists the most-cited. Even so, there are other explanations for this apparent difference in productivity, not related to aiding priority, namely that there are possible biases in the productivity measure. There are suggestions that US-based scientists disproportionately cite other US-based scientists (Leimu and Koricheva 2005). However, Wong and Kokko (2005) indicate that this is in fact a location bias: Europeans also disproportionately cite other Europeans. A second issue, regarding language, arises: the publications used for citation counts by the ISI being substantially in English. This may reduce the citation counts of those who publish in languages other than English (Van Leuween et. al. 2001), although articles in local languages would also be cited less as they are accessible to fewer readers. Van Leuween et al argue that the research impact of countries such as Germany and France would increase if more foreign publications were accounted for.

To investigate whether h-index productivity relates to other measures of productivity, we compared each country’s h-index rank to its patent productivity rank and its general productivity growth rates.

The results are that h-index rank positively correlates (0.66) with patent rank and with overall productivity for the majority of the countries (0.66, excluding Finland and Italy). Hence those countries with the highest average h-indexes also tend to have higher productivity measured in other ways. The patent productivity finding seems particularly relevant as it also measures R&D in which physicists are involved. This will, at least in part, be affected by the same incentives. Such an analysis suggests that the higher level of productivity shown in the US data is not substantially due to a US/English bias.

A natural question is whether the paper's finding of approximately equal productivities for migrants and non-migrants holds for elite scientists in other disciplines.

The only other data available to us are for bio-scientists. Again, these use ISI highly-cited scientists as the sample. Appendix Table A4 shows that, as with physics, it appears that movers and stayers have similar h-indexes. Further discussion for bio-sciences is contained in the unpublished report by Warwick University (2007).

Finally, a high level of elite mobility has also recently been reported for young economists in Oswald and Ralsmark (2007). Figure A1 reveals that in the top-10 US departments of economics approximately 75% of assistant professors did their first degree outside the United States. This is consistent with, although necessarily not precisely comparable to, the findings from our data on senior physicists.

8. Conclusions

This paper attempts to contribute to knowledge about the nature of the elite brain drain. It draws five conclusions.

First, the United Kingdom currently wins fewer Nobel Prizes in science than it used to[10], and the United States garners many more. What is less widely known is that, in both the UK and the United States, immigrant scientists win the Prize less often, proportionately, than in earlier decades. Second, by charting the careers of a group of distinguished physicists, we show that they are strikingly mobile. Almost half of the highly-cited scientists in our sample are migrants: our 158 physicists were born in 32 countries but now live in only 16. Approximately 30% migrated after their first degrees, and went predominantly to the US. Third, among highly-cited physicists the average productivity (as measured by a citations h-index) of movers is not different from that of stayers[11]. We are unable, with our data, to say whether migration itself causally increases a scholar's productivity, but it might be argued that

[10] Nevertheless, as a referee has emphasized to us, the UK still does well in most sciences by the standards of other European countries.

[11] This is somewhat against the spirit of, for example, Pierson and Cotgreave (2000), who focus, arguably a little strangely, on citations per paper rather than on total citations (their data show that stayers write more papers than movers, but the authors do not discuss this fact).

our results are consistent with Waldinger's (2008) finding that -- except for coauthors -- there are no strong externality effects among senior scholars. Fourth, international flows of physicists between first degree and the present day demonstrate that top scholars head to countries with high levels of R&D spending. Switzerland and the USA are the world's large importers, per capita, of elite physicists. CERN in Switzerland must play some role here, but, because of difficulties caused by multiple affiliations, we have not attempted to separate out those scientists. Fifth, we find evidence, from regression equations in Tables 6 and 7, that among elite physicists a current affiliation in the USA is associated with a 13%-19% higher h-index. This may be a genuine productivity difference, or reflect some form of pro-US citations bias, or some mixture of the two.

How, conceptually, can we make sense of the data? One way to view the findings on physicists is as supporting a theoretical model in which in the modern globalized world the costs of migration are low. Intuitively, the idea is the following. Consider a world with very high costs -- whether because of cultural differences across societies, or costly travel, or poor communication -- of switching between countries. Then only the very best workers will migrate. This is because they alone are the ones who will make a big enough return from international labour mobility to outweigh the high costs. In that case, migrants will be disproportionately from the top end of the ability distribution. They will be outstanding scientists with, in our terminology, particularly large h-indexes. Now contrast this with the case of low mobility costs. In that case, elite scientists of more average kinds of abilities, like the norm within the country into which they migrate, will find it rational to choose to switch nations. Hence mobile incoming scientists will be of similar quality to the average of those in the receiving nation, and most of these newcomers will not go on to win science prizes in the way that happened in an older world -- think of an early 20^{th} century setting of ocean liners and telegrams -- where mobility costs were high[12]. Any increases through time in the wage premium (p in our earlier notation) earned by distinguished scientists in the rich receiving countries will act to reinforce these tendencies.

[12] Although lower mobility costs alone do not imply that the absolute numbers of immigrant Nobel winners would fall.

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Table 1

The Number of Science Nobel Prizes Won by the United States Relative to the United Kingdom (1947-2006)

	1947-66	**1967-86**	**1987-06**
Proportion of UK-based Nobels as a % of US	44%	28%	8%
# Nobels won (US:UK)	45: 20	85: 24	112: 9
# Who were immigrants after their first degree	1: 1	3: 1	7: 0
# Who were immigrants after their doctorate	10: 2	22: 5	14: 0
Percentages of laureates who were immigrants	24%: 15%	29%: 25%	19%: 0%
#UK migrants to USA who won a Nobel	0	5	5

Notes

(i) US relative to UK numbers are expressed in this table as X: Y

(ii) The population of the US is now approximately fivefold that of the UK, so on arithmetical grounds in the current era the expected ratio is 5:1.

Source

Own calculations from www.nobelprize.org. Charlton (2007) uses different definitions and categories, and does not study immigrants.

Table 2

The International Distribution of Highly-Cited Physicists at Each Career Stage from Birth to the Present (% shares)

	At birth (32 countries)	**At BSc.** (30 countries)	**At PhD** (22 Countries)	**Now** (16 countries)
1st	USA (29.7%)	USA (43.0%)	USA (55.1%)	USA (67.1%)
2nd	UK (10.9%)	Germany (8.6%)	UK (8.9%)	Germany (7.6%)
3rd	Germany (9.4%)	UK (7.9%)	Germany (8.2%)	Switzerland (5.7%)
Others	50.0%	40.2%	27.8%	19.6%[13]

Notes

The top left-hand number of 29.7% means that at the point of birth the United States was home to 29.7% of those in our sample who would go on to become the world's most distinguished physicists. Today, as shown in the top right-hand number, 67.1% of the 158 live and work in the United States.

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

Table 3

Summary Data on Physicists' h-index Scores

Number of observations	158
Mean	58.97
Standard Deviation	13.52
Minimum	22
Maximum	115
Median	57

Table 4

Productivity Levels (as measured by physicists' h-index levels) Between those who Moved Country and those who did not Move

Stage	**Stayers** Average h-index if not moved country since the stage indicated	**Movers** Average h-index if moved country since that 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

Table 5

Migratory Groups and Average h-index Scores

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 6

Regression Equations on Physicists' h-indexes and Total Citations

(t-statistics in brackets; * indicates significant at the 5% level)

Dependent Variable: Log of 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	0.057	0.060	0.104	0.134	0.134
R^2_{adj}	0.051	0.046	0.084	0.107	0.101
Number of observations	158	138	138	138	138

Dependent Variable: Log 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	0.084	0.090	0.109	0.127	0.127
R^2_{adj}	0.078	0.077	0.090	0.101	0.094
Number of observations	158	138	138	138	138

Table 7

Alternative Regression Equations on Physicists' h-indexes

(t-statistics in brackets; * indicates significant at the 5% level)

Dependent Variable: Log of h-index

Constant	3.712* (43.28)	3.835* (53.23)	3.732* (47.75)	3.731* (47.35)	
Year since Phd	0.007* (3.14)	0.006* (3.10)	0.007* (3.34)	0.007* (3.38)	
USA Born – left USA (1 person)	-0.115 (-0.50)	-	-	-	
USA Born – stayed (40 people)	0.143* (2.28)	-	0.111* (2.38)	-	
USA Born – all (41 people)	-	-	-	0.103* (2.19)	
Migrated to USA at BSc (28 people)	0.185* (2.78)	-	0.155* (2.96)	0.153* (2.89)	
Migrated to USA at Phd (15 people)	0.159* (2.05)	-	0.129* (1.96)	0.126 (1.91)	
Migrated to USA post-Phd (22 people)	0.151* (2.13)	-	0.121* (2.10)	0.119* (2.05)	
Visited USA otherwise (33 people)	0.053 (0.82)	-	-		
R^2	0.133	0.057	0.127	0.122	
Adj. R^2	0.092	0.051	0.098	0.093	

Notes:

- Sample size is again 138
- There are 19 in the never been to USA category

Figure 1

The Funnelling of Elite Physicists Towards the USA

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%)

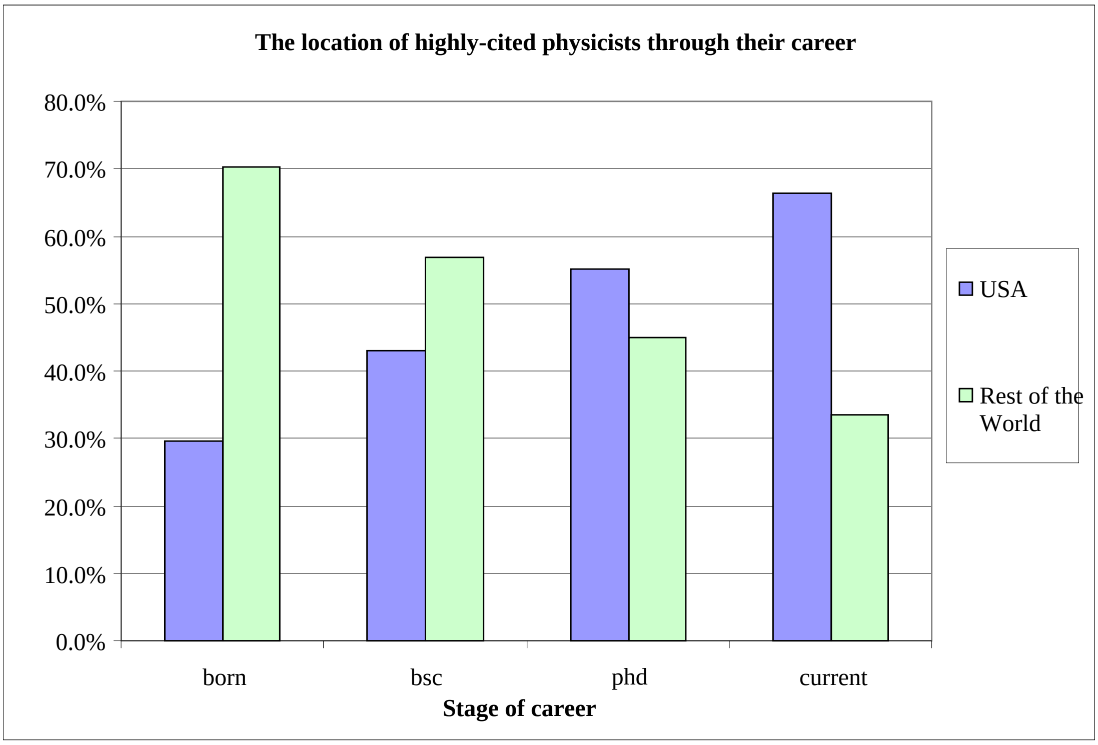
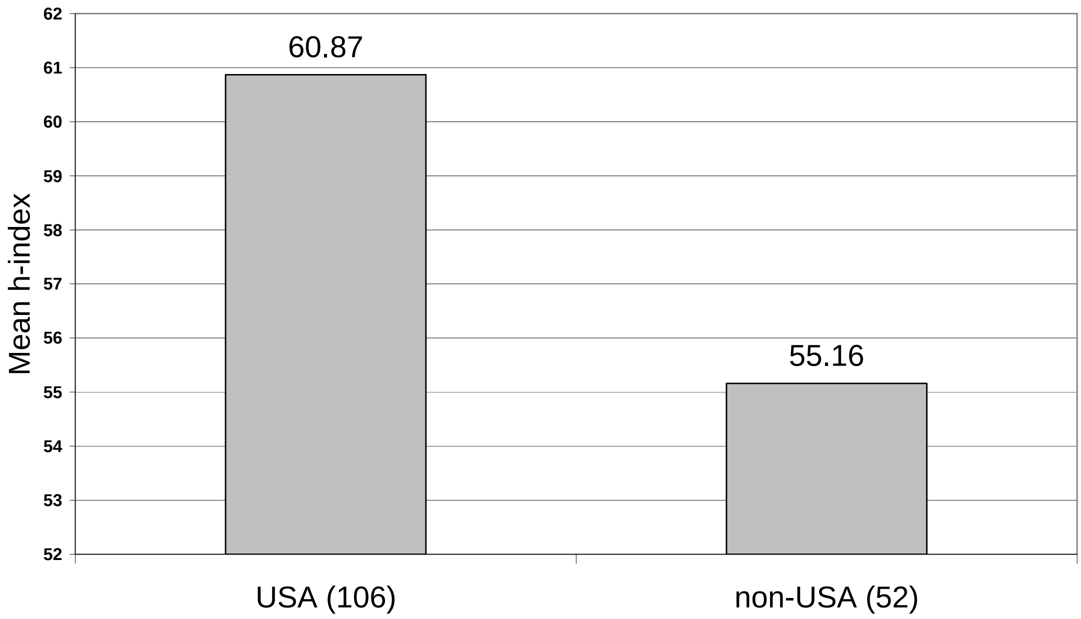


Figure 2

Mean h-index of Physicists by Current Geographical Location

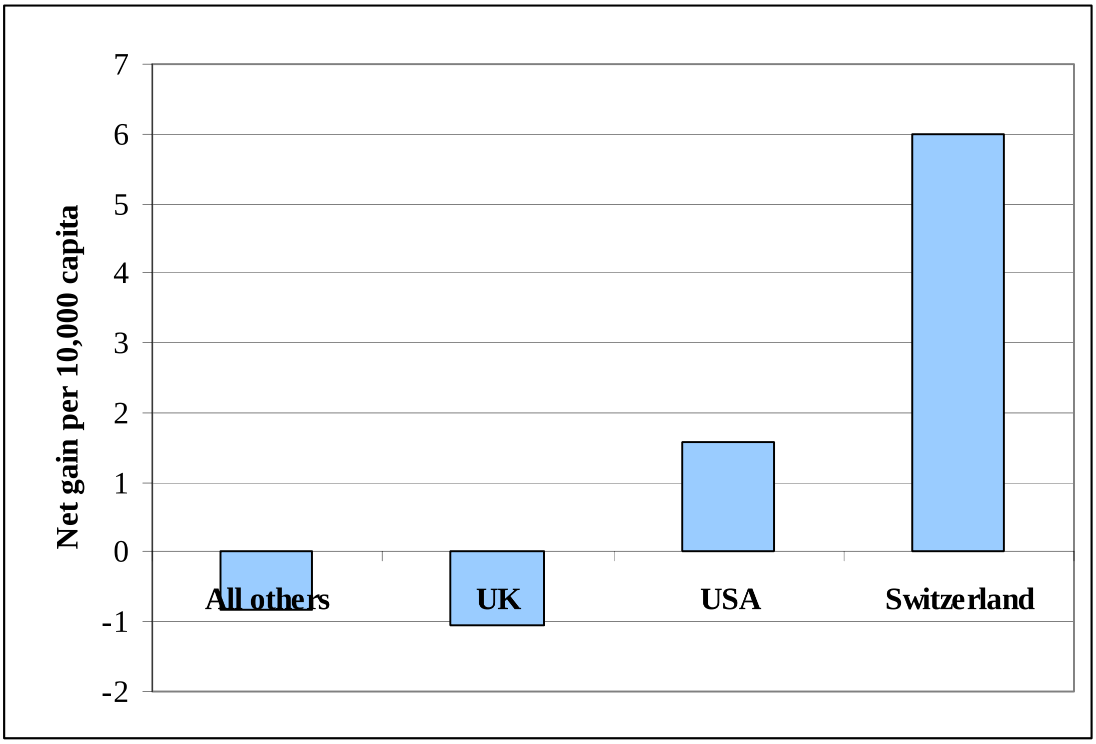


Note

This difference is not (quite) statistically significant at 5% on a 2-tailed test.

Figure 3

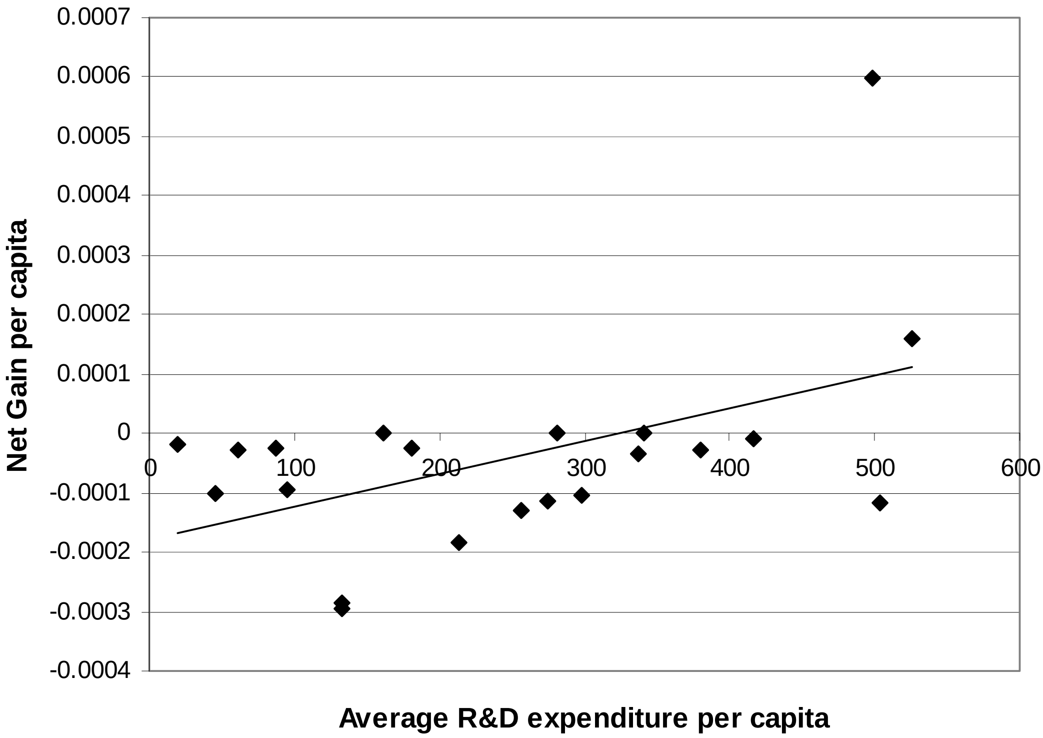
Brain-Drain Gains and Losses of Highly-Cited Physicists by Nation



Data scaled by 1,000.

Figure 4

The Relationship Between R&D Expenditure per capita[14] and Net Gain in Physicists



<u>Notes</u>

Each dot is a separate country. The extreme top dot in the north-east of the diagram is Switzerland.

[14] R&D expenditure as a percentage of GDP, GDP measured in US dollars, current prices and PPP's.

Figure 5a: The h-index Scores of Movers and Stayers in Europe and North America

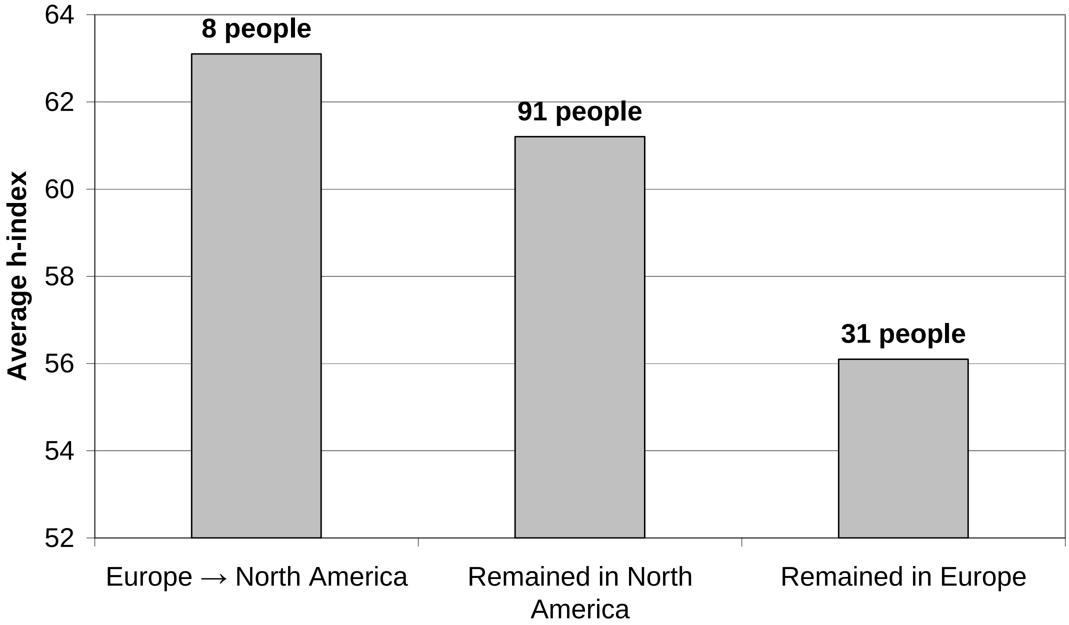
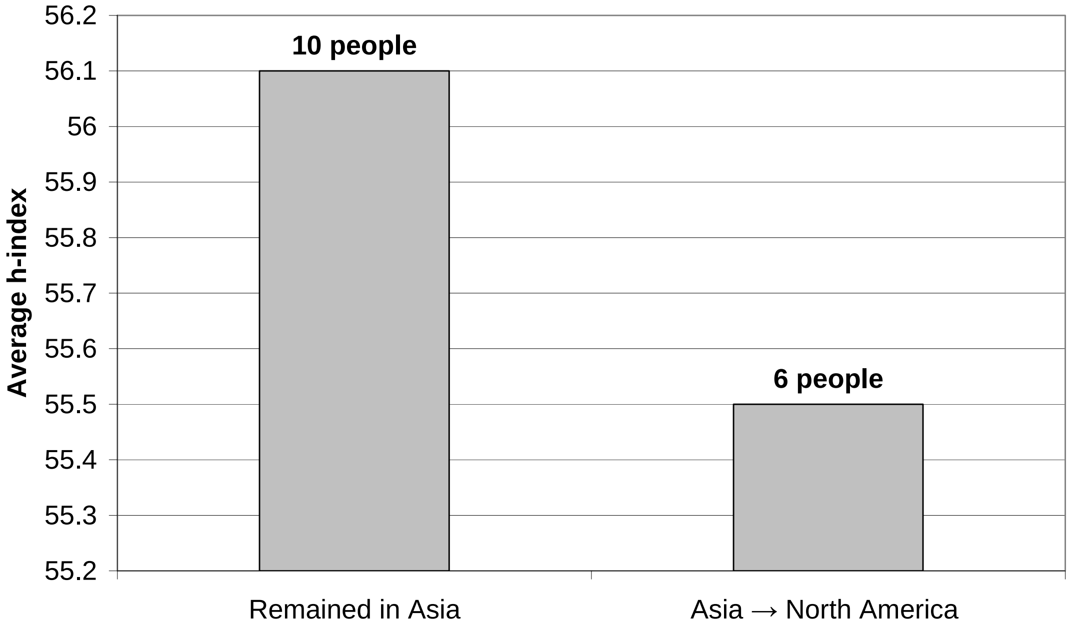


Figure 5b: The h-index Scores of Movers and Stayers in Asia and North America



Appendix

Appendix Table A1: Net Losses and Gains in Physics Researchers by Country

Country	Number after undergraduate BSc.	Number present day	Net gain	Net gain normalised by population
Australia	4	1	-3	-0.183
Austria	1	1	-1	-0.128
Brazil	1	0	-1	-0.006
Canada	5	2	-3	-0.112
China	2	1	-2	-0.001
Denmark	1	1	0	0.000
Finland	2	2	0	0.000
France	4	2	-2	-0.035
Germany	13	12	-2	-0.028
Greece	2	1	-1	-0.099
Hungary	1	0	-1	-0.095
India	2	0	-2	-0.002
Ireland	1	0	-1	-0.286
Italy	2	2	0	0.000
Japan	8	7	-1	-0.008
Rep. of Korea	1	0	-1	-0.024
New Zealand	1	0	-1	-0.029
Poland	1	0	-1	-0.027
Russia	2	0	-2	-0.013
Spain	2	1	-1	-0.026
Sweden	1	0	-1	-0.011
Switzerland	3	9	4	0.599
Turkey	1	0	-1	-0.018
UK	12	6	-6	-0.104
USA	65	106	39	0.158

Appendix Table A2: Comparison with Ioannidis (2004)

Finding	**This paper**	**Ioannidis - physics**	**Ioannidis - overall**
Sample size	158	46	1523
Moved since birth	44 %	50 %	33 (approx.)
US-born scientists who migrated	0 %	-	2 %
Females	0.63 %	-	3-4 %

Appendix Table A3: Summary Statistics – Highly Cited Physicists

Presently in the USA

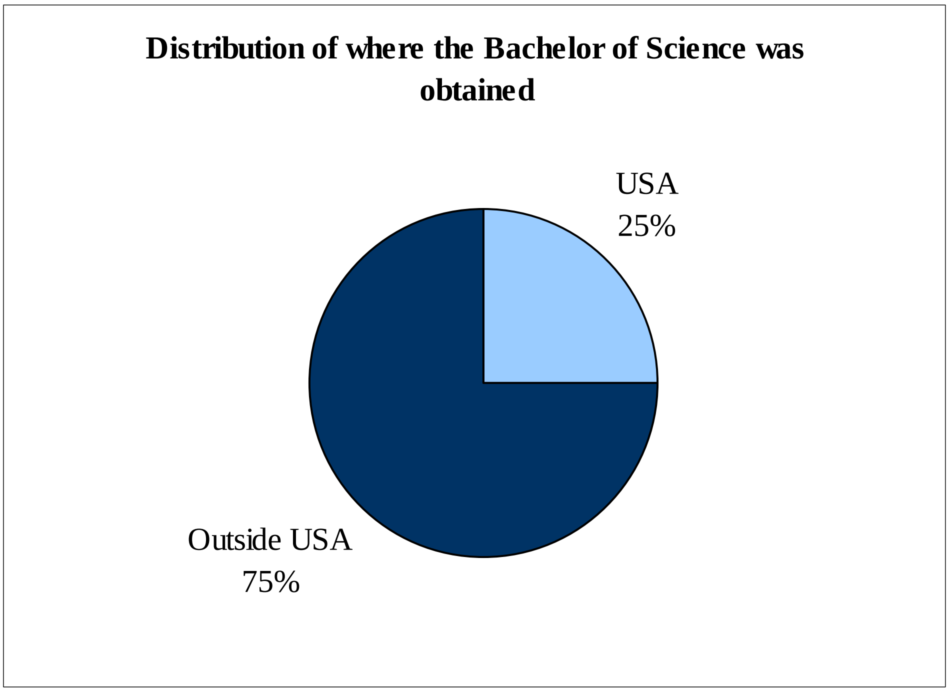
Variable	Observations	Mean	Std. Dev.	Minimum	Maximum
hindex	105	61.04	13.00	30	115
results	105	383.82	208.25	56	1248
avcite	105	57.52	36.56	15.74	216.84
totalcite	105	18458.52	13727.75	7409	135831
nocount	105	2.04	1.56	1	12
noinst	105	5.91	4.32	2	25
yborn	102	1947	9.928	1920	1976
ybsc	101	1968	9.39	1941	1986
yphd	105	1974	9.36	1947	1991

Presently not in the USA

Variable	Observations	Mean	Std. Dev.	Minimum	Maximum
hindex	53	54.89	13.72	22	85
results	53	445.60	270.99	82	1314
avcite	53	47.08	34.33	4.95	179.48
totalcite	53	15591.47	6757.03	2355	32714
nocount	53	3.15	1.89	1	10
noinst	53	6.26	4.44	1	21
yborn	50	1945	8.31	1926	1974
ybsc	44	1968	7.86	1951	1983
yphd	53	1972	7.99	1955	1987

Here, hindex is h-index; results is the number of papers; avcite is average cites per paper; total cite is total lifetime citations; nocount is missing; noinst is missing institution; yborn is year born; ybsc is year of BSc degree; yphd is year of PhD degree. Further details are available in Hunter (2007) or on request.

Appendix Figure A1: Measurement of the Brain Drain among Elite USA-Based Assistant Professors of Economics
Source: Oswald and Ralsmark (2007)



Note

This draws upon data on 112 assistant professors in the top-10 US departments of economics.

Appendix Table A4: The h-indexes of Highly-cited Bio-scientists Currently Working in the United States
Source: Warwick University (2007)

Sample size: 163

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