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MIGRATION CURRENTS AMONG THE SCIENTIFIC ELITE

ABSTRACT. Many countries today have policies to encourage outstanding scientists to remain, or return, 'home'. To date, the cumulative effect of these policies remains unclear. This essay argues that we need a new approach to studying elites in science. It draws upon three studies to suggest that migration is field-specific; that migration occurs more among potential, rather than among established elites; and that policies aimed simply at attracting eminent scientists may prove inadequate to the task of sustaining national scientific communities.

INTRODUCTION

In recent years, many Western countries have introduced measures to encourage outstanding scientists to return or remain in their countries of origin. In 2001, Germany's Federal Ministry of Education and Research (BMBF) announced a scheme to produce a 'brain gain' by acquiring foreign and German scientists working abroad.[1] The same year, the Australian Research Council created a new scheme of 'Federation Fellowships', which aims to 'provide opportunities for outstanding Australian researchers to return to, or remain in, key positions in Australia'.[2] Similar steps have been taken by other countries.[3] The reason usually given is that a 'brain drain' is occurring, and that the vitality of national science systems is threatened.

The question of international 'brain drain' has become a familiar feature in science policy for more than fifty years. Political and academic concern has usually focused upon large groups,

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[1] BMBF, '*Beitrag des BMBF zum Fragenkatalog für die öffentliche Anhörung, Chancen und Risiken der Informationsgesellschaft' am 28 Mai 2001* (Kdrs. 14/10b), (Berlin: Deutscher Bundestag, 2001), 7.

[2] Australian Research Council, 'Federation Fellowships', *Discovery Newsletter* (December, 2001), 1–2.

[3] J. Pickrell, 'Fighting Brain Drain – Ireland Gives Its Stars a Big Pot o' Gold', *Science*, 293 (5532), (2001), 1028–1029; Kirstie Urquhart, 'European Science – UK Unveils "Brain Gain" Initiative', *Science*, 289 (5480), (2000), 713–713; and D. Spurgeon, 'Canada Tries to Limit Nanotech Brain Drain', *Nature*, 408 (6812), (2000), 623–623.

defined by their educational and professional status, in terms of a 'highly-skilled workforce'. When scientists have been targeted at all, then they have been identified as members of large disciplines, such as physics or chemistry. However, new political approaches to the subject significantly differ in that they target very small groups (for example, Australia offers only about twenty Federation Fellowships each year). The underlying assumption is that a relatively small group – the scientific elite – is critical to the strength of a nation's science base. Attempts to reclaim this elite have become a new form of international competition.

Despite this interest, empirical evidence about the movements of elites, and their reasons for moving, remains scarce. While there is a widespread feeling that 'whoever can go to the USA does so and tries to stay there', we have at best only anecdotal evidence of this happening, and less to explain whether it does so across the entire spectrum of science.[4] It is not surprising that so little is known about the alleged causes of elite migration. The perspectives taken by international labour market and migration studies do not afford sufficient 'resolution' to identify such small and functionally specific groups as characterize 'elites', or to explain their net 'loss'.[5] Some studies have

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[4] For example, David Hume, 'Research Funding in Australia: Plugging the Brain Drain', *Search*, 25 (1), (1994), 27–31; M. Sincell, 'Why do the World's Leading Scientists Flock to the United States?', *Physics World*, 13 (8), (2000), 10–11; Alexander Hellemans, 'Beating the Brain Drain', *Naturejobs*, 414 (2001), 4–5; Sam Jaffe, 'Migrating Minds'. *Scientist*, 16 (9), (2002), 39–41; and Xavier Bosch, 'Brain Drain Robbing Europe of Its Brightest Young Scientists – Money and Independence Lure Young Researchers to the USA, Scientists Say', *Lancet*, 361 (9376), (2003), 2210–2211.

[5] Australian Society for Medical Research, *The ASMR Workplace Survey* (1999), cited at: *http://www.asmr.org.au/news/Wkplc/wshp.pdf*; Christoph F. Buechtemann, 'Deutsche Nachwuchswissenschaftler in den U.S.A. – Ergebnisse der Vorstudie', in Bundesministerium für Bildung und Forschung, *Deutsche Nachwuchswissenschaftler in den USA: Perspektiven der Hochschul- und Wissenschaftspolitik* (Bonn: BMBF, 2001), 19–89; Stifterverband für die Deutsche Wissenschaft, *Brain Drain - Brain Gain: Eine Untersuchung über internationale Berufskarrieren* (Kassel: GES, 2002); and Katja Schär, *Swiss Brains in the United States* (Basel: Gerbert RÜF Stiftung, 2002). A recent workshop at the New York Academy of Science, which focused on scientists' international mobility, concluded that the existence of a 'brain drain' to the USA remains an open question. Rabya S. Tuma, *Brain Circulation: Promoting Transatlantic Science, Academy Briefings* (New York: New York Academy of Sciences, 12 May 2004). A study of German postdoctoral fellows in the USA observed a general loss of scientists to the USA, but did not examine 'elites'. Jürgen Enders and Alexis-Michel Mugabushaka, *Wissenschaft und Karriere: Erfahrungen und Werdegänge ehemaliger Stipendiaten der DFG* (Bonn: Deutsche Forschungsgemeinschaft, 2004), 43–44.

been able either to identify elites, or to track the mobility of scientists, but none has succeeded in doing both simultaneously.[6]

It is obviously important for a country to determine whether it has a scientific elite, and if so, in what disciplines; and what factors keep it 'at home'. A recent investigation of the reasons why German scientists are slow to return home from the USA has listed several factors, including the lack of attractive research positions; the existence of 'age traps', which make it impossible to continue academic careers; the lack of ties to encourage reintegration; and the fact of better working conditions in the USA.[7] Scientists from the USA who have chosen to live permanently in France have listed several reasons, including comparatively better research positions, greater autonomy, family convenience, and quality of life. Some have also moved to, or stayed in France, when their research could not be pursued in the USA.[8] Such reasons are not captured by general surveys, and their impact upon individual disciplines has been obscured by the aggregation of data across fields.

One fundamental difficulty underlying the study of elite migration is the problem of definition. It is difficult to define an 'elite' in a way that satisfies empirical demonstration. The term 'brain drain' also tends to obscure rather than clarify because it is used to denote any loss of skilled workers. In order to understand the migration of elites, we need to apply methods that are sensitive to their specific attributes. The aim of this paper is to offer a theoretical approach, to derive a methodology, and to provide a limited answer to the question whether there is actually a problem of elite migration, and if so, whether current policies have any hope of resolving it.

[6] For example, Susan Crawford, 'Informal Communication among Scientists in Sleep Research', *Journal of the American Society for Information Science*, 22 (5), (1971), 301–310; P.M.D. Collins, G.K. Radda, J.H. Silverleaf, and D.C. Smith, 'Flows of Researchers to and from the UK', *Nature*, 328 (6125), (1987), 27–28; Paula E. Stephan and Sharon G. Levin, 'Exceptional Contributions to US Science by the Foreign-Born and Foreign-Educated', *Population Research and Policy Review*, 20 (1–2), (2001), 59–79.

[7] Buechtemann, *op. cit.* note 5, 73–80. Similar reasons were mentioned in the Swiss study; Schär, *op. cit.* note 5.

[8] Dominique Martin-Rovet and Timothy Carlson, 'The International Exchange of Scholars: The Training of Young Scientists through Research Abroad, 2. American Scientists in France', *Minerva*, 33 (2), (1995), 171–191, 183–186; Timothy Carlson and Dominique Martin-Rovet, 'The Implications of Scientific Mobility between France and the United-States', *Minerva*, 33 (3), (1995), 211–250; 246–247.

Conceptual Clarifications

Academic interest in scientific elites was first aroused by the work of American sociologists of science, notably including Harriet Zuckerman, and her study of Nobel Laureates. Zuckerman applied a familiar concept, proposed long ago by Vilfredo Pareto, that in every branch of human activity there is a class of outstanding individuals. Zuckerman defined an 'elite' as including those who have made a difference to the advancement of scientific knowledge, and has referred to Nobel Laureates as an 'ultra-elite'.[9]

These criteria – 'outstanding performance' (Pareto) and 'having made a difference to the advancement of science' (Zuckerman) – are difficult to operationalize, not least because performance is inherently difficult to measure. More important, such definitions reduce elite membership to one factor (performance), thereby neglecting the conditions of collective production. This factor has been emphasized by Michael Mulkay, who has characterized elite scientists as possessing four basic features:

- They are privileged with respect to awards and facilities, and are highly cited; they can, and usually do, control scarce resources.
- Their social ties with each other are stronger than their ties with other scientists.
- They control or direct the activities of others.
- They considerably influence recruitment.

The elite is concentrated in a few major centres where young scientists are selected and guided into fruitful research areas. This increases the likelihood that those scientists will later become members of the elite themselves.[10]

Mulkay's categories are useful because they make outstanding performance a necessary but not a sufficient condition for elite membership. A scientist must take part in knowledge production in a specific way in order to be regarded as a member of the elite. This factor introduces knowledge-producing collectivities as reference groups. Elite scientists govern knowledge production and

[9] Harriet Zuckerman, *Scientific Elite: Nobel Laureates in the United States* (New York: Free Press, 1977), 9–11.

[10] Michael Mulkay, 'The Mediating Role of the Scientific Elite', *Social Studies of Science*, 6 (3–4), (1976), 445–470, 446–454. That elite members produce other elite members was empirically confirmed by Zuckermann, *op. cit*. note 9, 99–100.

recruitment primarily within the knowledge-producing collective to which they belong that is, their specialty. A specialty comprises a community of scientists – that interacts in the production of knowledge. Scientific specialties are international, and are unevenly distributed across countries. From this perspective, there is no national scientific elite that consists of a 'country's best scientists', but rather there are many international scientific elites, of which there might be several, or only a few members in any given country. It is unlikely that every country has an elite in every specialty.

When we take into account these specific characteristics, it becomes apparent why the migration behaviours of elites have not been captured by science policy studies. Elite migration can be easily regarded as part of the overall problem of 'brain drain', but methods that focus upon general tendencies have failed to delineate specific groups. To date, even the most focused studies have captured only the 'performance elite', and not the 'functional elite'. To study the latter, we must delineate specialties, identify their elites, and analyse their distribution across countries.

A second limitation of 'brain drain' studies arises from the fact that elite migration forms part of 'normal' scientific mobility. There are, in fact, various 'mobilities', of which inter-organizational mobility is among the most important because it is vital to knowledge flows. However, it is clear that, as distinct from the overall requirement of mobility, some scientists choose to move to other countries and remain there. In such cases, *mobility* becomes *migration*. Crawford *et al.* define migration as 'the physical movement of people across national boundaries for extended periods of times', and suggest a definition of migration as involving a minimal absence of two years.[11] In practice, this period seems far too short because post-doctoral careers abroad often take longer than two years.

[11] The term 'mobility' is also used to describe cognitive changes in a scientist's work, such as 'intellectual mobility', see Terry Shinn and Georges Benguigui, 'Physicists and Intellectual Mobility', *Social Science Information*, 36 (2), (1997), 293–309; or such as 'interspecialty migration', see Daryl E. Chubin, 'The Conceptualization of Scientific Specialties', *Sociological Quarterly*, 17 (4), (1976), 448–476, 465–470. See also Elizabeth Crawford, Terry Shinn, and Sverker Sörlin, 'The Nationalization and Denationalization of the Sciences: An Introductory Essay', in Elizabeth Crawford, Terry Shinn, and Sverker Sörlin (eds.), *Denationalizing Science* (Dordrecht: Kluwer, 1993) 1–42, 25.

METHODOLOGICAL CONSIDERATIONS

Given this perspective, it follows that the 'tools of the trade' of international labour market and migration research are of little use to the study of elite migration. Researchers, let alone elite researchers, are not listed as a statistical category. Studies that delineate elites by applying the 'performance' criterion are plagued by difficulties in determining achievement. It is not surprising that the performance measures are rarely convincing.[12] Such studies also suffer from the limitations of a national focus, which leads them to be concerned with 'a country's best scientists', regardless of their standing in an international specialty.

Establishing the history of migration has also proved difficult. We may define stays in other countries as 'migration currents'. From a national perspective, there is a question of 'gaining' and 'losing' scientists from migration currents. However, the measures are too coarse to capture the specific migration current in which we may be interested. Categories such as 'foreign-born' apply to any move after birth, thus mixing causes of family migration with those of scientific migration.[13]

In order to identify the specific causal mechanisms at work in mobility and migration, the movements of people must be tracked over sufficiently long periods of time. Moreover, the 'tracking' of scientists' movements must be *complete* – that is, it must capture all individuals who are identified as being members of the elite. Since specialties can be small, and their elites even smaller, the absence of data cannot simply be dismissed as a statistical error. Conventional techniques using questionnaires or data from the Internet cannot guarantee completeness. Something else is needed.

In fact, for defining specialties, elites, and movements, bibliometric methods can be quite useful. First, they give methods to delineate specialties on the basis of citation relationships. Second, citations and co-citations can, in the statistical aggregate, measure

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[12] For example, Sami Mahroum has stated that recruitment from overseas by a British university makes a professor, a senior lecturer, or even a lecturer a 'star scientist'. See Sami Mahroum, 'Global Magnets: Science and Technology Disciplines and Departments in the United Kingdom', *Minerva*, 37 (4), (1999), 379–390, 381–382.

[13] See, for example, Virginia Trimble, 'Some Characteristics of Young vs. Established American Astronomers: Entering the New Century', *Scientometrics*, 48 (3), (2000), 403–411.

the influence of a publication and therefore of its authors.[14] They can also distinguish between general influences (as expressed by the overall number of citations) and influences within specific specialties (as expressed by citations by members of the specialty). Moreover, since databases usually contain addresses, these methods can track mobility.[15] The following three studies have applied bibliometric methods to gain preliminary answers to two questions: Are there 'migration currents' among elites that constitute a brain drain? What can bibliometrics tell us about elite migration?

These studies must leave unexplored a vital factor that cannot be assessed by bibliometric methods – namely, the causes of migration. Conventional investigations have used sampling techniques that are unrepresentative of elites. Moreover, the reasons for scientists' movements have been investigated by applying general questionnaires, which are of limited use where there are field-specific reasons. Overall, it seems wise to abandon pre-conceived notions about broad reasons for migration, and to explore specific work-related and personal motivations. This will require targeted interviews. In setting out methods for identifying migrants, the following studies may help to identify the kinds of people who should be interviewed.

Distribution of Elite Scientists

The study of scientific mobility reveals an inherent tension between theory and policy. While theory makes it clear that elite mobility and migration must be tracked at the level of scientific specialty, policy must consider the whole of the science system, comprising hundreds of specialties. To get an overall picture of the problem, we must identify the *distribution* of elites. Therefore, I analyse this factor as operating between the USA and other countries over a period of twenty years.

The measurement of global distribution requires a universally applicable indicator. I have used publications in leading multidisciplinary journals. This measure is not precise because it neglects the reception of publications. Its advantage, however, is that it enables

[14] See, for example, Anthony J.F. van Raan, 'In Matters of Quantitative Studies of Science the Fault of Theorists is offering too little and asking too much', *Scientometrics*, 43 (1), (1998), 129–139.

[15] For a more extensive discussion of these methodological problems, see Grit Laudel, 'Studying the Brain Drain: Can Bibliometric Methods Help?', *Scientometrics*, 57 (2), (2003), 215–237.

the identification of an 'international' elite, independent of a scientist's standing in a subspecialty. If a country's 'best scientist' in a given field does not produce outstanding results, he or she will not appear in a prestigious journal. Accordingly, I selected the two most internationally prestigious journals in science, *Nature* and *Science*.[16] Even though breakthrough work is also reported elsewhere, articles published in these journals are regarded as outstanding.

With a view to defining 'elites', I examined all articles and review articles published in the two journals between 1980 and 2002.[17] Since one contribution seemed too low a threshold to accord a scientist membership in an elite – and since some co-authors can be assumed to have made minor contributions – I set a threshold of three papers. This definition I assessed by varying the threshold (up to fifteen) and comparing the results. A major problem arises from the prevalence of homonyms (different authors having the same last name and initials). However, since names are a stable feature of national cultures, the resulting error is constant and may be neglected when analysing the dynamics of proportions of US versus non-US authors.

Papers published by elites, so defined, were then divided into three groups: publications with addresses of US institutions only; publications with addresses of only non-US countries; and publications having both US and non-US addresses. For articles having both US and non-US addresses, a fractional counting technique was adopted;[18] a publication with both US and non-US addresses was counted as 0.5 each.

The data in Figure 1 show that between 1980 and 2002, the number of articles by scientists in the 'US only' category in both journals decreased from 57% to 51%, and the number of 'non-US'

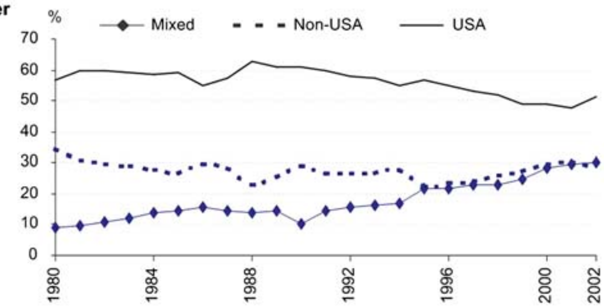
[16] Jointly, the two journals cover all major fields in science, albeit unevenly. According to the *Science* website (accessed on 28 October 2004), since the mid 1990s, a total of 32,535 articles have been published, 54% in the life sciences, 36% in the physical sciences, and 10% in other fields. *Nature* leans more strongly towards the life sciences, with only 1% of its research and review articles in physics (author's calculations).

[17] The data were retrieved from publication databases provided by the Institute of Scientific Information (ISI), namely the SCI on CD-ROM for 1980–1999 and the *Web of Science* for 2000–2002.

[18] This method was introduced by Nederhof and Moed to cope with publications where more than one country is involved. If authors from *n* countries participate in a publication, a country is assigned not the whole publication (1) but the proportion of $1/n$ (A.J. Nederhof and H.F. Moed, 'Modeling Multinational Publication: Development of an On-line Fractionation Approach to Measure National Scientific Output', *Scientometrics*, 27 (1), (1993), 39–52, 41). For the purpose of this investigation, the counting was reduced to two fractions, 'US' and 'Non-US'.

Figure 1. Nationality of 'Elite Authors' (having more than four publications) in *Nature* and *Science*.

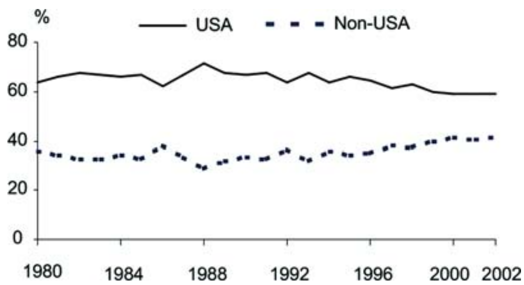
Year	Total number of articles
1980	1202
1984	1292
1988	1414
1992	1142
1996	1454
2002	1373
2002	1262



articles decreased from 34% to 28%. This result remained stable independent of the threshold applied. Thresholds of six, eight, ten, and fifteen publications provided the same trends, as did a fractional counting of the mixed papers. However, these statistics are influenced by the articles that were co-authored by US-based scientists with scientists from other countries. In order to control for varying numbers of US and non-US co-authors, I counted the number of US addresses and non-US addresses, rather than numbers of papers. The number of addresses roughly equates to the number of researchers.[19] A slight decrease in the number of US addresses can be observed (see Figure 2). A check with a higher

Figure 2. Addresses of 'Elite Authors' publishing in *Nature* and *Science*.

Year	Total number of articles
1980	1202
1984	1292
1988	1414
1992	1142
1996	1454
2002	1373
2002	1262



[19] Addresses and authors are not an exact match. Sometimes, authors have two different addresses, and the addresses of authors from the same institution and research group are usually given only once. However, as with the homonyms, it is assumed that the error is constant and thus does not affect the dynamics of proportions.

threshold (including only authors that have published at least fifteen papers) showed the same trend.

A third analysis assumed that authors of review articles, by virtue of having an overview of their field, can be regarded as members of their specialty elites. I selected all review articles published in both journals and counted their distribution according to address (US, non-US, and mixed). This did not show increased numbers of US articles.

In all three analyses, and regardless of using different criteria, and in spite of differences in the counting techniques, the result remained the same. The proportion of authors with addresses in the USA has not increased. There is thus no indication that the share of elite scientists in the USA has increased since 1980.[20] This observation contradicts the widespread perception of an 'elite brain drain' towards the USA. Non-US countries appear to have had at least as many elite scientists in 2002 as they had in 1980. However, since a very global measure has been applied to observe the global change in elite distribution, there may be several reasons why an 'elite brain drain' is invisible at this level.

First, a change of editorial practices in regard to non-US publications may mask a brain drain towards the USA. Second, increasing migration to the USA may be masked by an increase in the 'production' of elites outside the USA, a factor that would hold the average constant. Finally, it is possible (and even likely) that different specialties will show different trends. The simple observation that no 'elite brain drain' can be discovered at the global level of authorships in elite journals requires examination at the level of the specialty. For this reason, I have conducted two case studies.

[20] In particular, there is no indication that the end of the Cold War has affected the international distribution of the scientific elite. This is not surprising because the socialist science system never played a significant role in world science. Bibliometric data have shown the discrepancy between their publishing activities and the perception of their contributions by other scientists, as measured by citation (T. Braun, W. Glänzel, H. Maczelka, and A. Schubert, 'World Science in the Eighties: National Performances in Publication Output and Citation Impact, 1985–1989 versus 1980–1984', *Scientometrics*, Part I, 29 (3), (1994), 299–334; Part II, 31 (1), (1994), 3–30).

THE ANGIOTENSIN ELITE

In the first case study, I explored elite movements in a biomedical specialty that has emerged around a common research object, the hormone Angiotensin. I examined this specialty using bibliometric data combined with data about participants who attended a special conference series, the so-called Gordon Conferences.[21] I find these conferences particularly useful for identifying elites because the organizers invite only those scientists who have made outstanding contributions. Lists of participants (including information on institutional affiliations) are easily retrieved from the web at *http://www.grc.uri.edu/*. I selected a list of 215 chairs, vice chairs, discussion leaders, and speakers from the six meetings that took place between 1996 and 2002 (there was no conference in 2000). This list was reduced by ranking mutual citations and co-citation links between 1990 and 2002. Authors who ranked 150 or better on both lists were selected as the elite. This yielded a list of 130 scientists. Since the threshold was arbitrary, I repeated the procedure using a threshold of 100, which produced a list of eighty-seven scientists.[22]

These eighty-seven scientists were then traced for international mobility, using address information given in the biomedical database *PubMed*, which lists the first-author institutional affiliation of all publications indexed since the mid 1980s. Where a given scientist was not a first author, I traced addresses from the on-line or paper copy of the journal. Additional data, obtained from the Internet, were used to check whether changes in institutional affiliations corresponded to real movement. The starting point was the country where the scientist undertook his or her PhD.[23] Where this information was unavailable, the institutional address of the first publication was used instead.

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[21] For a more detailed description of the methods and the reasons for choosing them, see Laudel, *op. cit*. note 15.

[22] I disregarded the general Anglo-Saxon bias in the SCI because, in the two specialties investigated, English has been the dominant language and thus the language of the field. A specific US bias might lead to an over-emphasis of US-based elite members. However, the relative stability of proportions of elite members obtained by applying different thresholds indicates otherwise.

[23] I have used the PhD as a starting point because the existence of a postdoctoral phase is evidence of an intent to continue a scientific career, while other postgraduate studies are undertaken for a variety of reasons. In medical areas, scientists sometimes have a medical degree as their highest degree. In these cases, I have used the medical degree as a starting point.

The data in Table 1 set out the migration pattern of Angiotensin researchers over a period of forty years, using the larger list of 130 and the smaller list of eighty-seven.

TABLE 1

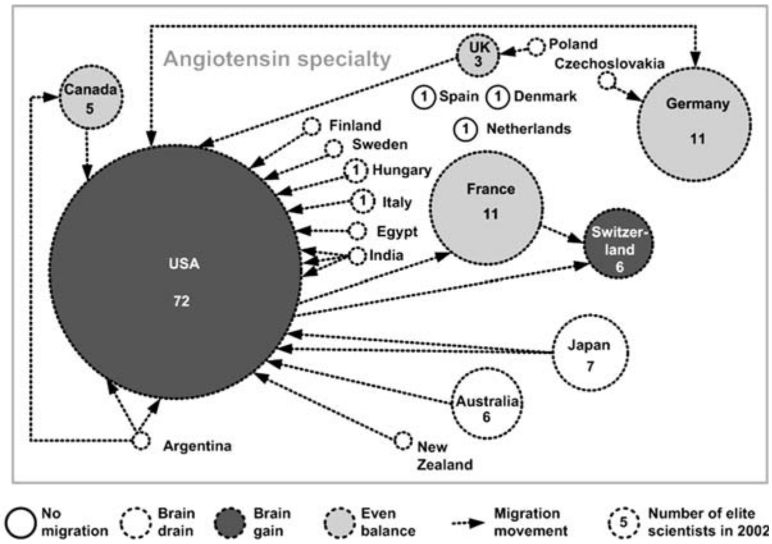
Mobility of Angiotensin Elite Researchers

	130 elite scientists (threshold = 150)	87 elite scientists (threshold = 100)
Always lived in the USA	58 (45%)	43 (49%)
Migrated to the USA	17 (13%)	13 (15%)
Stay temporarily in the USA	17 (13%)	11 (13%)
Migrated from the USA to other countries	3 (2%)	2 (2%)
Migrated from other countries to other countries	4 (3%)	3 (3%)
Live in other countries	31 (24%)	15 (17%)

Both lists show the same tendency. A large proportion of the Angiotensin elite is American, and has always lived in the USA. The USA has also attracted many elite scientists in this field – even after subtracting the three who emigrated from America. Of the seventeen scientists who moved to the USA and who are still there, twelve have stayed more than fifteen years; one for ten years; two for more than seven years; and two for about five years. Thus, the majority appear to have migrated permanently.

The data in Figure 3 also show that the remaining fifty-eight members of the Angiotensin elite are concentrated in a very few countries outside the USA, including France, Germany, Japan, Australia, Switzerland, and Canada. The only country apart from the USA that is absolutely gaining elite scientists is Switzerland. Germany, France, and Canada retain equal balances. The others have lost at least one. Some countries (UK, Australia, Japan) are relative losers (losing elite members, but retaining some), while others have lost all their elite members. All of the developing countries belong to the latter group, with Argentina and India having lost three each.

Figure 3. Permanent Migration of the Angiotensin Elite in 2002.



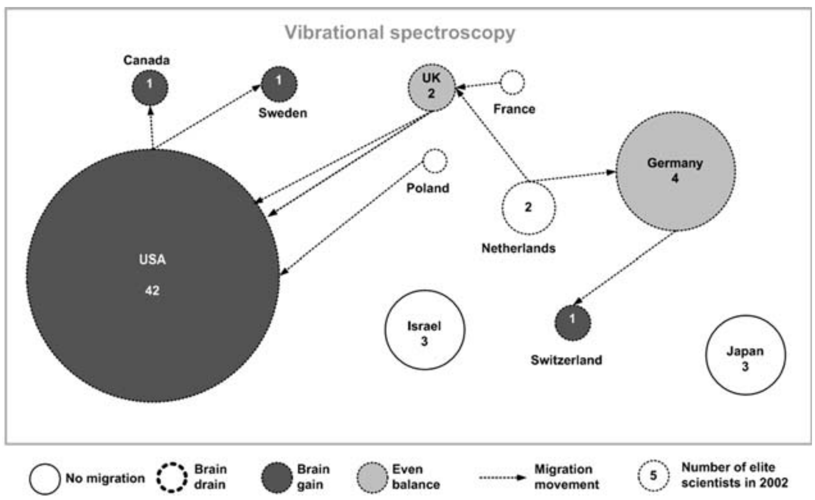
THE VIBRATIONAL SPECTROSCOPY ELITE

A second example of an 'elite in motion' is the field of Vibrational Spectroscopy (VS), a specialty within physical chemistry that uses spectroscopic techniques to analyse molecular motion. Data from Gordon Conferences in this specialty suggest that it is smaller than the Angiotensin field. Using the same methods, I examined participant lists from four conferences between 1996 and 2002, and selected 110 scientists. From citation and co-citation analyses, those ranking in the first seventy-five on both lists were selected, yielding a final list of sixty-four. A physical sciences publication database (INSPEC) was used to track their movements.

From the sixty-four identified as elite scientists, forty-two have always lived in the USA (with three having been temporarily in other countries); eleven have moved to the USA, three of whom are still there; eight others have returned to their home countries; four have moved from the USA; and eight have remained in or moved to countries other than the USA.

VS differs from the Angiotensin specialty in that nearly two-thirds of its elite are USA-based and have always lived in the USA. Indeed, Figure 4 shows that the field is concentrated in the USA, Germany, Israel, and Japan. The USA gained three members of the elite, but also lost two. In the Angiotensin specialty, fewer than half of the elite have always worked in the USA. Even if we consider that the VS elite is only half the size of the Angiotensin elite, its migration currents are very weak and do not have significant directions. If we sum all migration movements, the USA gained only 1.6 per cent of the VS elite, compared to 10.8 per cent of the Angiotensin elite. This confirms that the 'elite brain drain' is field-specific at the level of specialties, and may be strong in some, but completely absent (or even reversed) in other specialties.

Figure 4. Permanent Migration of Elite Scientists in Vibrational Spectroscopy in 2002.



Characteristics of Migrants

Moving beyond movements, let us consider other characteristics. Bibliometric methods can help us to understand migration by providing information about migrants. In this context, it is instructive to relate 'visibility' with spatial mobility. The concept of 'visibility' was introduced by Cole and Cole, who suggested that scientists are 'functionally visible' when other scientists make use of their work, as indicated by citations.[24] To assess visibility, I counted citations to the work of the fifteen Angiotensin and the five VS scientists who migrated after 1980. Self-citations were excluded. Because it was not possible to identify citations from the specialties,[25] total citation counts had to serve as a rough indicator of visibility.

In eight of the twenty cases, the year of migration was identified from the Internet. For the rest, the year of migration was assumed to be one year before the appearance of the first article published with a new address. The beginning of a research career was dated from the year of first publication in *PubMed* or *Inspec*. By comparing citations, we can distinguish three categories of migrants:

(a) migrants who had very few citations before migration;
(b) migrants whose citations (and 'visibility') were increasing; and
(c) migrants who were already highly cited when they moved.

Table 2 gives an example for each group. Table 3 shows that few migrants were already members of their elite when they migrated. The others were either relatively unknown or had just begun to be visible. The interval between first publication and the year of migration suggests that these began their careers in the country to which they migrated.

TABLE 2

Examples for Three Groups of Migrants from the Angiotensin Specialty

Move from to	Before ...	1980	81	82	83	84	85	86	87	88	89
(a) India → USA			[a]	2	0	0	2[b]				
(b) France → Switzerland			[a]	1	1	0	6	5	15	13[b]	
(c) USA → Germany	(1974)[a]...	227	228	289	321	301	321	437	481	577[b]	

[a]Year of first publication
[b]Year of migration

[24] Stephen Cole and Jonathan R. Cole, 'Visibility and the Structural Bases of Awareness of Scientific Research', *American Sociological Review*, 33 (3), (1968), 397–412, 400.

[25] In order to identify citations from the specialties, it would be necessary to delineate them and to identify all their members. This cannot be done since bibliometricians have yet to develop satisfying methods for delineating specialities (Laudel, *op. cit.* note 15).

TABLE 3

Citation Rates of Migrants Who Now Belong to the Elite at the Time of Migration

Citation rate	Moved to USA	Moved from USA	Moved between other countries	Average time span between first publication and year of migration (years)
(a) Low	7	0	0	4
(b) Increasing	0	1	3	6
(c) Very high	0	3	1	13

Two deviant cases were excluded, namely scientists from former socialist countries who had been active researchers for a long time prior to migration but were hardly visible. Scientists from former socialist countries took part in knowledge production, but most had poor visibility because of travel and communication restrictions.

Analysing data about twenty-two migrants confirms that those who migrated to the USA did so at an early stage, shortly after finishing their PhDs in their home countries. Thus, it is usually not the current elite who migrate, but rather the younger scientists – that is, the potential elite – who later become 'elite' in the country to which they move.

The situation was different for those who moved in the opposite direction – that is, from the USA to other countries. Four of the five scientists were already highly cited when they emigrated. CV data reveal that these scientists began their research careers in the USA. Thus, having become 'elite' in the USA, they returned either to their country of birth (Canada, France, Germany, Sweden) or to a country close by (for example, born in Austria, moved to Switzerland).

Comparisons

A comparison between these specialties suggests one reason why an 'elite brain drain' is not observed at the macro-level. The Angiotensin specialty shows evidence of an 'elite brain drain', but such a trend in VS is so weak as to be non-existent. The comparison also suggests that an 'elite brain drain' in some specialties may be made completely invisible at the global level by counter-currents in other specialties, or by changes in national 'elite production rates'.

Case studies such as these direct our attention away from unspecified concerns about a general 'loss of elite scientists', towards the field-specificity of underlying migration currents. From our knowledge of differences between specialties, there emerges a huge range of possible factors, all of which merit investigation. For instance, frequency, and intensity of collaboration varies among specialties. Collaboration is usually linked to stays overseas, and to the exchange of doctoral students, both of which may trigger migration. Another factor arises from the distribution of the elites itself. The two cases confirm the conclusion that new elite members are recruited by current elites. From this it follows that 'elite production' is autocatalytic, and that a country needs elites to generate elites.

Funding can be assumed to be a third field-specific factor. This is important, because it seems clear that migration occurs not so much among elites, but rather among scientists who have lower visibility or who are yet to become visible. What is commonly viewed as a 'loss of scientific elites', is actually the loss of potential elites, most often to the USA. Searching for attractive options typically includes a postdoctoral period overseas.[26] There, scientists with the potential to become members of the elite are given the opportunity to do so. Since this selection takes place principally in the USA (and to a lesser extent in the UK, Germany, and Switzerland), an 'elite brain drain' results.

In this context, it becomes obvious why present policies to re-attract elite scientists are not likely to reverse the 'brain drain'. If it is necessary to have elites to generate elites, it is also necessary to have attractive working conditions for potential elites. The reasons given by scientists in explaining why they return to their home countries suggest that scientists who potentially belong to elites see a trade-off between working conditions and cultural preferences.[27] A prime task for science policy lies in securing better conditions. Apart from targeting small special groups, it seems to be necessary to increase the attractiveness of the national science base as a whole.

Conclusion

This paper has studied a very small set of scientists who form the 'elite' strata in two specialties. While these represent only two of hundreds of specialties, the results are sufficiently coherent to highlight the importance of elite 'migration currents', and the value of supplementing conventional brain drain studies with detailed inves-

[26] Buechtemann, *op. cit.* note 5, 73–75.
[27] Stifterverband, *op. cit.* note 5, 86; Schär, *op. cit.* note 5, 19.

tigations of small decisive groups, which are otherwise lost in statistical categories. If we accept that a specialty's elite has a governing and regulating function, then the loss of members of this elite will have serious implications for knowledge production. However, the role of national subspecialties in international knowledge production has not been well studied.[28] Therefore, the consequences of losing an elite can be predicted in only a very general sense. A country's subspecialty is uncoupled from frontier science, standards evaporate, and the country is no longer able to recruit or train the best young scientists in this field. At what stage the accumulation of these effects has broader repercussions for the national science system as a whole, has yet to be determined.

These small case studies lead to two major conclusions. First, they demonstrate that we can measure a 'brain drain' of elite scientists that is not visible at the macro-level, and that this very specific brain drain is distributed unequally among different specialties. Science policy measures to alleviate 'elite brain drain' can be successful only when we know why scientists actually migrate, and why they do not return. However, one must go beyond general assessments of the science system and general descriptions of working conditions. Given the different migration patterns in different specialties, it can be assumed that reasons for migration are at least partly field-specific. A search for reasons has to examine the working conditions and decisions of individual scientists, which can be done only by qualitative methods.

Second, it seems clear that, as expected, the 'elite brain drain' works in the direction, and to the advantage of the USA. The USA has both a significant proportion of scientific elites and a comparatively 'rich' science system. However, it also appears that migration to the USA occurs less often when scientists are already members of an elite. It is the potential elite rather than the actual elite that moves, and recruitment into the elite appears to turn mobility into migration at the same time.

Overall, it may be argued that 'elite brain drain' studies such as this are important not only for science policy. Our knowledge of elites, their structure and function, is still very limited. If they are indeed an important link between international specialties and na-

[28] Jochen Gläser, 'Scientific Specialties as the (Currently Missing) link between Scientometrics and the Sociology of Science', in Mari Davis and Concepción S. Wilson (eds.), *Proceedings of the 8th International Conference on Scientometrics and Informetrics* (Sydney, 16–20 July 2001), 191–210, 203.

tional sub-specialties, their close study should provide valuable insights into the relationship between international and national scientific communities.

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