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Abstract

It is widely recognised that knowledge and highly skilled individuals as "carriers" of knowledge (i.e. knowledge spillover agents) play a key role in impelling the development and growth of cities and regions. In this paper we discuss in a conceptual way the relation between spatial movements of talent and knowledge flows and present empirical results on the geography and mobility patterns of star scientists. Our findings show that these phenomena a highly uneven in nature, benefiting only a few countries which are capable to act as magnet for scientific talent.

1 Introduction

In the past years, there has been a growing recognition that knowledge and highly skilled individuals as "carriers" of knowledge are a key driving force for regional development, growth and innovation (Lucas 1988, Romer 1990, Glaeser 2004, Florida 2002a, 2005a). Given the importance of well-educated people for regional dynamism, the geography of talent and the mobility patterns of the highly skilled class are increasingly attracting the attention of both academic scholars and policy agents. The central purpose of this paper is to get a better understanding of the nature of spatial movements of talent and to discuss their implications in terms of knowledge transfer. We refer to talented individuals who transfer knowledge from one place to another by means of their mobility as "knowledge spillover agents". Although the paper deals with highly skilled mobility and migration in general, a particular attention will be paid to flows of star scientists. Understanding the precise character, spatiality, and temporality of this phenomenon is essential for explaining regional growth patterns and uneven development. In this paper we will deal with the following questions:

- How could we conceptualize the role of highly skilled labour for regional development and growth?
- Which factors are essential for attracting and retaining the highly skilled class? Which determinants shape the migration and location decisions of talented scientists?
- Which features characterise the geography of star scientists and their spatial mobility patterns?

The remainder of this paper is organised as follows: Section 2 provides the conceptual framework and reviews the literature. We examine the role of highly skilled labour for regional dynamism, the relation between labour mobility and knowledge spillovers and the key factors for attracting and retaining talent. Section 3 presents the empirical analysis of the paper which focuses exclusively on star scientists as a specific group of talent. Based on an analysis of the database *ISI HighlyCited.com* we demonstrate that the spatial distribution and mobility patterns of star scientists are highly uneven at the global scale. Section 4 summarizes the main findings and draws some conclusions.

2 Mobility of talent, star scientists and knowledge spillovers: Theoretical background and literature review

2.1 The role of highly skilled labour for regional development and growth

In the past two decades a considerable body of work has enhanced our understanding of the critical role played by human capital and talent in spurring regional development, innovation and growth. Highly qualified people and human talent are acknowledged to be an essential economic asset and a source of creative power in science, technology and business (Straubhaar 2001; Solimano 2005). The new growth theory (Romer 1990) formally highlights the connection between knowledge, human capital, and economic growth. Drawing on the insights of this conceptional work, Lucas (1988) has put forward the argument that the spatial concentration of (skilled) labour generates strong external economies (or in his words "external human capital"), and that these externalities increase productivity and growth. In the meantime there exists a large number of empirical studies providing evidence for the strong relationship between well-educated people and the performance and growth of cities and regions (Eaton and Eckstein 1997, Black and Henderson 1999, Glaeser et al. 1995, 1998, 2000, 2004; Glendon 1998, Glaeser and Saiz 2004; Rodriguez-Pose and Vilalta-Bufi 2005). Looking specifically on high-technology or knowledge-based sectors, it has been shown that a flexible labour market and highly-qualified personnel play a central role for the emergence and dynamics of high technology industries (Keeble and Wilkinson 2000). A survey of Californian biotechnology companies, for example, has revealed that the availability of qualified workers is a key factor determining the location of these firms (Audretsch 2003). Florida's recent work on the creative class (2002a, 2002b, 2005a, 2005b) supports the above raised issues, as it also identifies human capital as the driving force behind regional development. His research indicates that the economic geography of talent exerts considerable effects on the location of high-technology industries and regional incomes. Although Florida's creative class approach has been criticised sharply for a variety of reasons (see, for example, Glaeser 2004; Lang and Danielsen 2005; Peck 2005; Boyle 2006; Hansen et al. 2005; Markusen 2006; Scott 2006), his basic ideas on the significant role played by skilled labour for regional economic dynamism continue to be highly influential, both in the scientific and policy community.

What are the specific contributions of highly qualified scientists to the innovation performance and dynamics of cities and regions? Already 40 years ago, Horowitz (1966) analysed the economic effects of the regional distribution of scientific talent and concluded that areas which are rich in scientific talent can derive subsequent economic benefit while those which are poorly endowed with scientists suffer economic loss. More recently, in a series of articles Zucker and her colleagues showed for the rapidly advancing science and technology area of biotechnology that star scientists making major discoveries play an important role, influencing the use of the new technology by firms (Zucker and Darby 1996, 2001, 2006; Zucker et al. 1998a, 1998b, 2002, Darby and Zucker 2001, 2006a). Zucker and Darby (1996) and Zucker et al. (1998) introduced the concept of biotechnology stars based upon productivity measured by the number of articles written through the 1990s which reported a genetic-sequence discovery. Direct involvement of these stars proved to be a major factor in determining which firms were ultimately major winners in biotechnology (Zucker et al. 1998, 2002; Zucker and Darby 2001). In a recent paper Zucker and Darby (2006) extend the concept of star scientists to all areas of science and technology. They demonstrate that the number of stars in a U.S. region or in one of the top-25 science and technology countries has a consistently significant and quantitatively large positive effect on the probability of firm entry in the same area of science and technology. Their main result is that the number of star scientists and engineers active in a region or country has uniformly very significant (at the 0.001 significance level) and positive effects on the probability of a firm entering in all six science and technology areas investigated. These findings lead them to conclude that the stars themselves rather than their potentially disembodied discoveries play a crucial role in the formation or transformation of high-tech industries, emphasising their embodied knowledge, insight, taste and energy. The physical presence of star scientists, thus, matters, as it has an impact on the formation and transformation of high-tech firms. The evidence provided by Zucker and Darby (2006) strengthens the case for the importance of the work of these extraordinary individuals for the economic development of regions and nations. Given the crucial role played by talent in general and star scientists in particular in fuelling regional dynamics, their mobility patterns and location decisions turn out to constitute essential issues which deserve closer attention.

2.2 Labour mobility as a key mechanism of knowledge spillovers

In the last years, the nature and geography of knowledge flows have become an important research topic in regional studies (see, for example, Bathelt et al. 2004; Gertler and Levitte 2005; Gertler and Wolfe 2006; Maskell et al. 2006; Tödtling et al. 2006; Tödtling and Trippl 2007, Trippl and Tödtling 2007). A key argument which has been raised in the recent literature on the mechanisms of knowledge flows and knowledge circulation is that it is not only market transactions and networking which matter for the exchange of ideas and expertise. There seems to be a widespread consensus that also spillovers constitute an important type of and specific channel for knowledge transfer and that these externalities have a positive impact on innovation and growth (Breschi and Lissoni 2001a, 2001b; de Groot et al. 2001; Bottazi and Peri 2003; Greunz 2005; Maier and Sedlacek 2005; Eckey et al. 2005; Abdelmoula and Bresson 2006).

Knowledge externalities are complex in nature as they can take very different forms. There are, for example, spillovers through the reading of scientific literature and patent specifications (Jaffe 1989; Jaffe et al 1993), through informal contacts (Feldman 2000), through observation and monitoring of competitors (Malmberg and Maskell 2002) or through spin-offs (Keeble and Wilkinson 2000, Tödtling et al. 2006). The mobility of highly skilled personnel (or the transfer of human capital) represents another core mechanism for the spilling over of (embodied) knowledge (Arrow 1959; Matusik and Hill 1998, Rosenkopf and Almeida 2003; Döring and Schnellenbach 2006).

In the following our focus is exclusively on the mobility of highly qualified workers as a specific type and manifestation of knowledge spillovers. We refer to talented individuals who transfer knowledge from one place to another by means of their mobility as “knowledge spillover agents”. To understand the precise character, spatiality, and temporality of this phenomenon is essential for explaining regional growth patterns and uneven development.

2.3 The geography of knowledge spillovers through mobile labour

The movement of highly-skilled workers between local firms, universities and other organisations is regarded to constitute a central mechanism of regional collective learning and localised knowledge transfer (Saxenian 1994, Henry and Pinch 2000, Keeble 2000, Lawton Smith and Waters 2005), underpinning the dynamic development of high-technology clusters. Mobile highly-skilled researchers, scientists, engineers and managers are important “carriers of knowledge” (Lorenz 1996) on the local labour market, leading to an enhanced transfer of embodied expertise and a deepening and broadening of the regional pool of knowledge.

Labour mobility, however, is not restricted to the local or regional levels. On the contrary, the international migration of labour has become an important form of globalisation in recent years (Beaverstock 2002; Willis et al. 2002; Global Commission of International Migration 2005; Freeman 2006; OECD 2006; Taylor 2006). Particularly interesting for the purpose of this paper is the increase of the global mobility of highly skilled managers, scientists, and engineers[1] (Iredale 2001; OECD 2005). There is a growing global competition for talent and highly qualified people (Mahroum 2001, Cervantes and Goldstein 2006). Over the last two decades a global “migration market for skills” (Salt 2005) has emerged. The main driving forces of this trend are a growing demand in advanced countries for IT and other skills in science and technology as well as the emergence of more selective immigration policies that favour highly skilled migrants (Cervantes 2004, Salt 2005). Indeed, in recent years, the (international) mobility of highly qualified workers and the issue of an effective utilisation of their skills have captured the attention of policymakers in both advanced and developing nations and regions (Lowell 2001, Auriol and Sexton 2002, Wickramasekara 2002, OECD 2004; Reitz 2005). Many countries have implemented policies and programmes to facilitate the international recruitment of highly qualified people (OECD 2005). Mahroum (2001, p. 27) states that “immigration, particularly of the highly skilled, is becoming increasingly an inseparable segment of national technology and economic development policies.”

International migration and mobility of people are powerful mechanisms for the global diffusion of cutting-edge scientific, technical and managerial knowledge (Bunnel and Coe 2001; Coe and Bunnel 2003; Williams 2007), underpinning innovation in “traditional high-tech centres” such as Silicon Valley (see, for example, Alarcon 1999, Saxenian 1999) and impelling the emergence of new dynamic agglomerations of knowledge-based industries as has been shown for the IT industry in several Asian regions (Saxenian 2002, 2005, 2006).

2.4 Directions of knowledge flows and spillovers through movements of highly skilled workers

Several authors have argued that knowledge spillovers through mobile talent are far from being one way flows but tend to be more multi-directional in nature (Meyer et al. 2001; Ackers 2005a), leading to a sharing of the benefits of skilled migration between sending and receiving countries and regions (see, e.g., Fromhold-Eisebith 2002; Wickramasekara 2002; Meyer 2003; Regets 2003). These insights stress the need to go beyond a strict dichotomy

[1] Although the focus of our paper is on the migration of highly skilled, we agree with Williams (2006) who argued that every migrant and not only the highly educated one is a knowledge carrier, exhibiting a potential to transfer knowledge to others.

between “brain drain” and “brain gain” when assessing the consequences of international migration of highly skilled workers. Terms such as “international brain exchanges” (Salt 2005) or “brain circulation” (Saxenian 2000) can be found in the literature as denominations for this phenomenon. The trend towards circulation is strongly linked to the changing temporality of skilled labour migration, which is about a shift from longer-term to shorter term mobility (Koser and Salt 1997; King 2002). As Williams et al. (2004, p. 28) put it: “Longer-term migration has increasingly been replaced by more diverse, shorter-term flows, so that it is more apposite to refer to circulation and mobility than to migration”.

The return of highly qualified people to their home countries represents an important example in this context. The cases of India, Taiwan, Israel and Eastern Europe clearly show that such return flows of talent can even constitute an economic development strategy in its own right (Saxenian 2002, 2003, 2005; Cervantes and Goldstein 2006). Recent academic work has demonstrated that the sending countries or regions might also benefit from their “knowledge migrants” (Ackers 2005a) even if they do not return. Highly relevant in this context is the rise of diaspora networks which connect skilled expatriates with their country of origin, alleviating the negative effects of the loss of highly qualified persons for the sending area (Meyer 2001, Ackers 2005b; Gill 2005). A study carried out by Agrawal et al. (2003) identified the existence of knowledge spillovers from the receiving region to the sending one. Agrawal and his colleagues have developed a model of knowledge spillovers that rests on social relationships between inventors. In this model, geographical proximity is crucial for the emergence of social ties, but the authors allow for the possibility that social ties endure even after individuals have become separated. Based on an analysis of patent data, Agrawal et al. (2003) found strong evidence in support of the enduring social capital hypothesis: social ties that promote knowledge transfer persist even after formerly co-located individuals are separated. Thus, at the regional level, there is a spillover from the region that receives the employee to the region that lost the employee. Similar findings have been presented by Corredoira and Rosenkopf (2005), who analysed the mobility of technical employees among firms in the U.S. semiconductor industry between 1980 and 1995. They show that a firm experiencing a loss of an employee is more likely to cite the firm receiving the mobile employee. Interestingly, the authors found that this effect is stronger for firms that are geographically distant than for firms that are spatially proximate. To summarise, the “circulation phenomenon” manifests itself in a variety of ways and seems to be to some extent “decoupled” from the physical presence of talent. Although high-skilled international migration has gained considerably in importance, its economic and other effects are under-researched and remain poorly understood (Regets 2001; Coleman and Rowthorn 2004). A notable exception is, for example, the work of Ottaviano and Peri (2005, 2006) and Peri (2006) who show empirically for the USA that the inflow of foreign-born workers is associated with economic gains.

2.5 Understanding scientific mobility

Highly skilled migrants are far from being a homogeneous group. On the contrary, there are marked differences between professions regarding, for example, their propensity and motivations to move abroad (Mahroum 2000a; Iredale 2001, see also Section 2.7). Scientists and academics tend to be more mobile than talent belonging to other highly skilled categories (Meyer et al. 2001), indicating the significance of an increasingly global research labour market (Ackers and Gill 2005). The enormous imbalances in the geography of such flows and the resulting uneven distribution of scientific capabilities have become a key issue of policy debates in many countries and regions (Gill 2005). In Europe, for example, the ongoing loss of scientists to the United States is a matter of constant concern (Morano-Foadi 2005).

Generally, scientific mobility, or – as Meyer et al. (2001) put it – "scientific nomadism" is regarded to be a normal phenomenon in the academic world and often a precondition for progression in science careers, entailing international flows of scientific knowledge. Laudel (2003, p. 215) noted that "the interorganisational mobility of scientists has always been an important functional requirement for science. Scientists 'on the move' bring their knowledge to other places, acquire new knowledge in the new place and thus promote new combinations of knowledge. This is especially important in knowledge is not communicated through other channels like publications ... Since some kinds of knowledge are circulated in science by scientists who travel around, scientists' interorganisational mobility constitutes one of the most important knowledge flows in science."

Scientific migration and mobility, however, are a highly complex phenomenon. A sound understanding of its impact requires more than simply enumerating emigrants, immigrants and returnees. The effects of scientific mobility critically depend on factors such as the skill levels involved and the temporal character of such movements (see also Ackers and Gill 2005). Recent research also indicates that mobility patterns differ enormously within the academic or scientific sector between disciplines, scientific specialities and countries (Ackers 2005a, Laudel 2005). A key finding of recent studies and analyses concerns the significance of the "qualitative dimension" of scientific migration. It is not only the quantity but also the quality of flows that matters (see, for example, Ackers 2005a). In terms of regional and national development, it seems to be obvious that movements of the most brilliant and brightest scientists have the greatest impact. Salt (1997, p. 22) noted that "the departure of a few top-level specialists in certain sectors of basic research could lead to the collapse of national scientific schools". In this context Mahroum (2003) points to the attraction of global centres of excellence. These centres have a "magnetic" and multiplying effect drawing star scientists who play an essential role in subsequent recruitment: "They tend to go where the best facilities are, and their reputation attracts the best young talents" (Mahroum 2003, p. 2).

Laudel (2005) points explicitly to the role of the "scientific elite" in recruiting the next generation of star scientists, emphasising the autocatalytic character of "elite production". The elite, she argues, is spatially concentrated in a few places "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" (Laudel 2005, p. 380). Using bibliometric methods she also found that elite migration is partly field-specific and, even more interestingly, that migration occurs more among potential elites rather than among established elites.

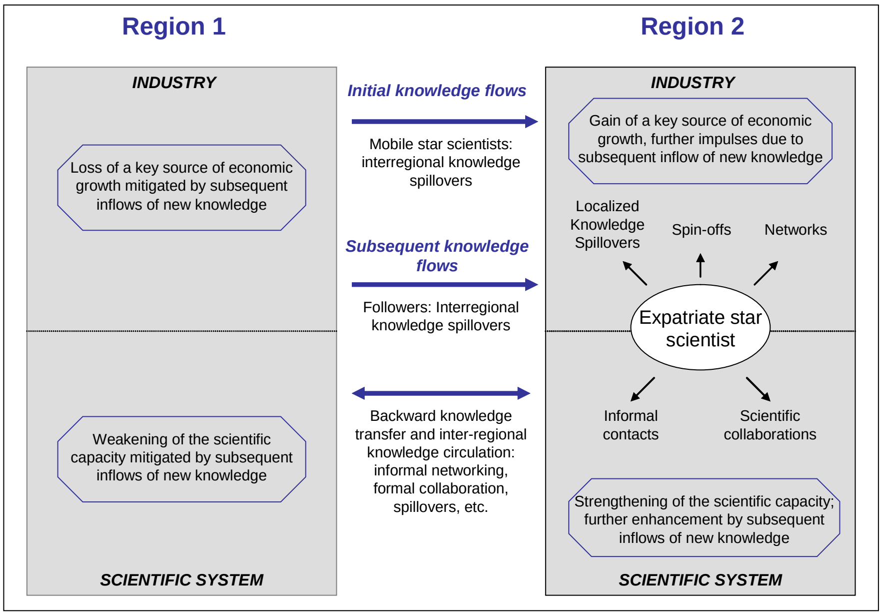
2.6 Star scientists, knowledge flows and regional development

The issues raised above enable us to be more specific about the nature of knowledge flows which result from the mobility of highly skilled people and to reflect upon their impact on regional development. Focusing on movements of talented scientists we propose a model of knowledge circulation that goes beyond a simple and unidirectional transfer of knowledge (see Figure 1).

The model suggested in this paper recognises that mobile star scientists can give rise to a large variety of interregional and local knowledge flows and it explicates important types in this respect. In the following we intend to discuss in a more comprehensive way the issue of interregional knowledge interactions induced by the movement of talented scientists and to draw first conclusions about their impact on regional development and innovation.

In order to unravel the multitude of interregional and international knowledge interactions which can be related to mobile star scientists, our model draws a distinction between "initial knowledge flows" and "subsequent knowledge flows". The model is, therefore, dynamic, and this allows for capturing the complexity of the phenomenon dealt with here.

Figure 1: Knowledge link model



Source: Own compilation

- The movement of a star scientist from Region 1 (sending region) to Region 2 (receiving region) is inextricably linked to an interregional spilling over of knowledge. To take into consideration only this first effect, however, is oversimplified and would imply to ignore the large variety of knowledge flows that is potentially set off by the mobile scientist. To put it differently, the initial interregional knowledge spillover effect that is due to the movement of a star scientist could entail a range of further knowledge interactions between the sending and the receiving region.

- These subsequent knowledge flows emphasised above can take different forms. Other talent from Region 1 might follow the star to Region 2, thus, generating a further series of knowledge spillovers from the sending to the receiving area. These "followers" can include, for example, members of the former research team of the star scientist or also talented students.

- Furthermore, there are strong reasons to assume that the star maintains his or her relationships to the academic and industrial world of the sending region, releasing a backward transfer of knowledge or the establishment of linkages promoting the interregional circulation of expertise. There are various manifestations which can make their appearance in this context, such as scientific or R&D co-operations or more informal contacts promoting the exchange of expertise and ideas.

Mobile star scientists, therefore, can pave the way for an intense interregional and international exchange of knowledge and competences. They play an important role for the establishment of "knowledge infrastructures" which are pivotal for gaining a competitive edge in the contemporary economy. Mobile stars could be regarded as important "creators of knowledge roads" between regions, along which other talent can drive and knowledge can move easily, tying distant areas together.

In our model we differentiate between effects on the economy and effects on the scientific system in both the sending and receiving region. Before doing so, it should be alerted that the strength of the effects depends upon the scientific and economic specialisation and the knowledge bases of the respective area, its absorptive capacity as well as the duration of time the star stays in the region.

- Arguably, there is a strengthening of the science base in the receiving region and correspondingly a weakening of scientific capabilities in the sending region due to the movement of the star scientist. This initial effect is reinforced if the "follower phenomenon" is quantitatively and qualitatively strong. The existence of mechanisms for backward knowledge transfer and interregional knowledge circulation, however, can mitigate the problem, leading to "scientific gains" for both the sending and the receiving region. The latter will in particular benefit from the immigration of the star scientist, if his or her knowledge diffuses locally. This requires an embedding of the star into the local or national scientific community, brought about by the formation of research co-operations, informal relationships and other types of scientific collaboration with local colleagues.

- Dealing with the economic impact of the mobility of star scientists, it seems to be reasonable to argue that the sending region looses a key source of innovative dynamism, whereas in the receiving region the arrival of the star might imply positive impulses for the local industry. Provided that the star scientist does not cut all ties to his or her former home region, an interregional circulation of knowledge can set in, stimulating creativity and economic development in both the sending and the receiving area. Examining in more detail the potential effects for Region 2 leads us to note that their emergence hinges on the successful creation of efficient mechanisms for the economic exploitation of scientific knowledge. These can comprise academic entrepreneurship, i.e. the foundation of a new firm by the star, formal and informal networks between the star scientist and the local industry, membership of the star in advisory boards of science-based firms, various forms of localised knowledge spillovers (e.g. citations of publications and patent specifications), etc. Consequently, only "embedded stars" who establish a range of contacts to actors in the host region will potentially act as an engine of growth, whereas "isolated stars", who lack such essential linkages will probably set off only a few economic effects.

In the following Section we will discuss those factors which attract and retain highly skilled migrants and scientific elites.

2.7 Attraction and mobilisation of talent: Which factors do really matter?

Which factors attract highly-skilled labour and, consequently, shape the economic geography of talent? This question is of outstanding importance, given the importance of knowledge spillover agents for regional innovation, growth and development. Among academic scholars, however, there is little consensus on this crucial issue.

According to the empirical findings of Florida (2000) the location of talent is strongly influenced by high levels of "diversity" (low entry barriers for human capital). To put it differently: talented people are attracted to locations that display a high degree of demographic diversity, i.e. places, where anyone from any background, race, ethnicity, gender, or sexual orientation can easily plug in. Other factors such as climate, cultural, and recreational amenities, in contrast, seem to play only a minor role. The experiences of Korea and Taiwan are also interesting for the question dealt with here. Wickramasekara (2002) argues that active government programmes combined with special incentives were essential in attracting (back) skilled persons. Moreover, the rapid growth of the local economy, the high priority given to R&D, and the establishment of industrial parks (e.g. the Hsinchu Industrial Park in Taipei), and initiatives by private sector industry which went "head-hunting" for talent in developed countries promoted the inflow of (returning) skilled people. Cervantes (2004) – however without any reference to empirical work – lists a multitude of factors including amongst others job opportunities, quality of working conditions, wage differentials, etc. Furthermore, he notes that for researchers and academics the conditions in the host country regarding support for research and demand for R&D staff and professors can be an important determinant in the migration decision and destination.

General claims such as those summarised above, however, conceal that the phenomenon of skilled migration is complex and diverse in nature, as it comprises very distinct groups of mobile professionals. This accentuates the need of a more differentiated approach for identifying and evaluating those factors which attract highly qualified talent. Mahroum (2000a) developed a typology of skilled migration and argued convincingly that each group of mobile professionals is driven by different push and pull factors (see Table 1).

Table 1: A classification of highly skilled mobility and types of influencing factors

Group	Type of Push & Pull Factors
Managers and executives	Benefits and remuneration
Engineers and technicians	Economic factors (supply and demand mechanisms) The state of the national economy
Academics and scientists	Bottom-up developments in science Nature of conditions of work Institutional Prestige
Entrepreneurs	Governmental (visa, taxation, protection etc.) policies Financial facilities Bureaucratic efficiency
Students	Recognition of a global workplace Accessibility problems at home Intercultural experience

Source: Mahroum (2000a)

As shown in Table 1, the group of academics and scientists, which is of special relevance for the aim of this paper, is mainly lured by bottom-up developments in academia and science, favourable working conditions, and the prestige of the host institution (Mahroum 2000a). In particular the latter aspect seems to be significant. Drawing on empirical results Mahroum (2000b) demonstrates that a high reputation of an academic or scientific institution can serve as important magnet of mobile talented scientists. This underscores the essential role of global centers of scientific gravity as a key location factor.

Looking specifically at the location preferences of star scientists, Zucker and Darby (2006) show that stars are attracted by places which host more other stars. Star scientists tend to move from areas with relatively few peers to those with many in their scientific field. Consequently, this implies a concentration of stars over time. Millard (2005) examines the mobility of scientific researchers in the EU within the context of the clustering of science and R&D in particular geographical areas. Reporting on a case study of Italian researchers who moved to the UK, the location decisions of this group of researchers based on the clustering of R&D in Europe and in the UK are analysed. The results point to the importance of prestige and networks in determining location decisions and these factors give established research centres an important advantage over smaller, developing ones. Other empirical work supports the view that non-economic determinants play a crucial role in shaping international movements of academics. A study of the migration motivations of highly skilled migrants in the United Kingdom identified three groups of factors which influence scientific mobility. These comprise (1) aspects of employment (career advancement opportunities, the existence of global centres of excellence, wage differentials, and quality of research facilities); (2) economic and quality of life factors (i.e. living conditions) and (3) personal development associated with travel and experiencing another culture (DTI 2002). A European Science Foundation report also stresses the significance of issues of status and autonomy which are not directly related to economic rewards. Martin-Rovet (2003, p.1) noted that "researchers want centres of scientific excellence and access to the best and latest scientific equipment. They want increased research funding and better salaries. They look for a society where science is respected and where their social status is esteemed". Finally, also Williams et al. (2004) stress that systemic features (greater openness in research agendas, career structures etc.) and reputations for excellence serve as main factors for attracting academics and scientists. Flows of highly skilled scientists, they add, tend to be highly localised in knowledge-intensive clusters. These inflows exhibit a cumulative character, as the presence of talent enhances the attractions of the key destination spaces for subsequent inflows. The preliminary literature review of empirical studies has revealed that we still have a poor knowledge about those factors that attract and retain skilled workers and star scientists. Based on the work mentioned above, we might argue tentatively, that the results which have been found for the often broadly defined group of "talent" or "skilled personnel" do not necessarily hold true for the star scientists. There seems to be a widespread agreement in the literature that for the latter group, the presence of centres of scientific excellence constitutes the main factor of attraction. To examine the locational preferences of this type of knowledge spillover agents in more detail and to analyse which locational factors act as "magnets" for these experts and "knowledge carriers" is, thus, a key challenge for future research activities.

3 Empirical Analysis

We will deal with a specific aspect of the mobility of star scientists in the empirical section of this paper: their spatial distribution and their mobility patterns. By focussing on these aggregate aspects, we leave aside some elements of the theoretical discussion above like motivation, location factors, knowledge spillovers and regional development. These aspects will be the topics of later parts of the ongoing research.

3.1 Methodology

A crucial element in an investigation of the spatial distribution and mobility of star scientists is that of how to operationalize a star scientist. In this paper we consider the authors of highly cited research papers as they are identified by *ISI HighlyCited.com* as “star scientists”. This definition may be decisive for the further results of our analysis. Therefore, we describe some key aspects of the database, the changes we made to the data, and some sample characteristics in the remainder of this section.

Given the available information, in the empirical analysis we have to treat the designation of the star scientists as exogenously given. Based on this implicit assumption we will discuss the spatial distribution and mobility of these star scientists. This would be unproblematic if individuals would become star scientists only based on their personal abilities. In reality, however, whether a certain researcher becomes a star scientist also depends upon things like education, training, research environment and opportunities. These may differ substantially by location such that location and mobility of researchers may be an important factor in their chance of becoming a star scientist. It is important to keep this in mind when interpreting the empirical results of our analysis.

3.1.1 ISI HighlyCited.com – The Database

ISI HighlyCited.com is an online information service provided by the *Institute for Scientific Information* (ISI), a subsidiary of *Thomson Incorporated*. With this freely accessible website one can identify individuals, departments, and laboratories that made important contributions to the advancement of science and technology in recent decades. The importance of contributions is identified by the number of citations they generated in journal in ISI databases. These databases also provide the raw material for various citation indices and for impact factor measures.

ISI HighlyCited.com distinguishes 21 different areas of research (S*ubject Categories*) such as Clinical Medicine, Engineering, Physics or Social Sciences and identifies approximately the 250 most cited individuals in each category. The information in *ISI HighlyCited.com* is based on publications and citations from the period 1981-2002. Later years are currently been worked on. The quantitative approach and the extensive – but not very current – observation period represent a limitation in contrast to alternative (e.g., survey based, qualitative) approaches. On the one hand, older researchers with an extensive publication record may have a better chance of being classified as star scientists because of the extensive observation period. Certain researchers and scientists who belong to the very top of their class are not included because they do not yet have accumulated enough publications and citations. For example, John C. Mather, Nobel-prize laureate 2006 in Physics, does not belong to the star scientists, according to this definition.

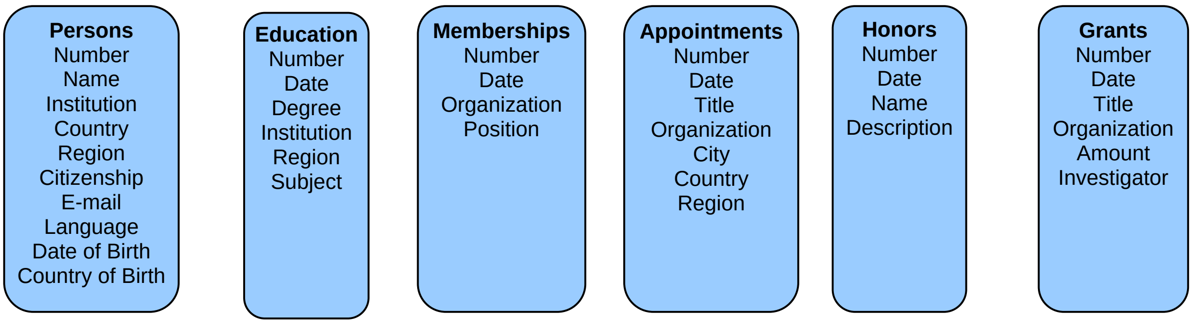
To date the platform includes approximately 5,600 star scientists, comprising less than 0.5% of all publishing researchers. For 61% of all registered star scientists there is additional biographical information available including data on educational background, faculty and professional positions, memberships and offices, personal contact etc. The responsibility for data maintenance and updates remains with each individual. As a consequence the dataset is lacking in up-to-dateness, coherence/standardization and completeness.

3.1.2 Data preparation and processing

We transferred the information available in *ISI HighlyCited.com* into a database structure consisting of the 6 tables shown in Figure 2. The relevant tables for our analysis are *Persons*, and *Education* as they reveal information about the spatial distribution and the mobility patterns of star scientists.

To facilitate our analysis, the dataset it had to be adjusted. We closed information gaps whenever possible, e.g., by deriving the name of the *country* from the information in *institution* (e.g., Harvard University → USA). Spatial information was standardized (e.g. US, U.S. or United States → USA) and typing errors were corrected. Additional spatial information was added by categorizing *countries* into *regions* in order to facilitate comparison (e.g. France, Germany, Austria, Spain, etc. → Western Europe). A complete list of regions and their respective countries is given in the appendix.

Figure 2: The structure of the *ISI HighlyCited.com* database



3.1.3 Sample characteristics

The dataset of our analysis consists of all the 5,570 star scientists registered in *ISI HighlyCited.com*. 58.5% of the star scientists report 3 educational achievements, in average 3.3 per person. Since the published information is under the editorial control of the individuals themselves the records differ in up-to-dateness. 42.5% of the star scientists have last updated their personal information in 2003, 16.5% in 2004 and only 18.5% in 2005 or later. Almost one quarter of the star scientists (22.5%) have not updated their records since 2002.

Regarding the age structure, we find a strong overrepresentation of researchers over 50 (see Table 2). The finding seems to reflect the quantitative approach underlying the compilation of the dataset. An increase in age likely leads to an increase in the number of publications consequently resulting in an increased chance of being cited. As hypothesized above, higher age increases the chance of being categorized as star scientist. This is clearly a limitation of the database as it limits the chances of younger researchers to be included.

Table 2: Age structure of the sample

Year of birth (Age)	*Relative (Absolute)*	*Year of birth (Age)*	*Relative (Absolute)*
1917 – 1925 (89-81)	**2.0%** (47)	**1946 – 1955** (60-51)	**42.8%** (1,011)
1926 – 1935 (80-71)	**10.8%** (255)	**1956 – 1965** (50-41)	**8.7%** (205)
1936 – 1945 (70-61)	**35.7%** (840)	**1966 – 1978** (40-28)	**0.2%** (4)
Sum		100% (2,362)	
No record		(3,208)	
Total		(5,570)	

When comparing the age distribution of star scientists over subject categories, we can identify "old" and "young" research areas. Using a Chi^2-Test we find a highly significant ($Chi^2 = 181$, DF = 100) relationship between age and subject category. Table 3 shows the cells with the highest (**1**) and second highest (2) difference between the observed number of star scientists and the respective expected number as it is calculated for the Chi^2-Test. Particularly "old" subject areas are Agricultural Sciences, Chemistry, Microbiology, Neuroscience and Physics as opposed to others such as Computer Science, Ecology & Environment, Geosciences, Mathematics and Molecular Biology & Genetics where star scientists tend to be much younger.

Table 3: “Old” and “young” subject categories

Subject Category	**1917-1925** (89-81)	**1926-1935** (80-71)	**1936-1945** (70-61)	**1946-1955** (60-51)	**1956-1965** (50-41)	**1966-1978** (40-28)
Agricultural Sciences		**1**	2			
Biology & Biochemistry			**1**			2
Chemistry		2	**1**			
Clinical Medicine		2		**1**		
Computer Science				**1**	2	
Ecology & Environment				**1**		2
Economics & Business	2			**1**		
Engineering			**1**		2	
Geosciences				2	**1**	
Immunology		2		**1**		
Materials Science		**1**			2	
Mathematics				**1**	2	
Microbiology		**1**	2			
Molecular Biology & Genetics				2	**1**	
Neuroscience	2		**1**			
Pharmacology			**1**		2	
Physics	2		**1**			
Plant & Animal Science				**1**		
Psychology & Psychiatry	2			**1**		
Social Sciences, General	2			**1**		
Space Sciences			**1**		2	

1 – strongest
2 – second strongest

3.2 Results

In this section we will present the main results of our analysis concerning spatial distribution and mobility of star scientists. In the first part we will look at the spatial distribution patterns of star scientists, in the second part the focus will be on their spatial mobility.

3.2.1 Spatial distribution of star scientists – A static view

The US play a dominant role regarding the spatial distribution of star scientists (see Table 4). Hosting 66.2% of all star scientists the US take the overwhelming lead among all nations. Other western industrialized countries follow far behind with UK (7.6%) being in second and Germany (4.2%) in third place. The top ten countries account for 94.2 percent of all star scientists. The remaining 5.8% include 31 out the 41 countries with star scientists and entirely contain regions like Central & South America, Central & Eastern Europe, Africa, and Asia.

Table 4: Ranking by Country and Region

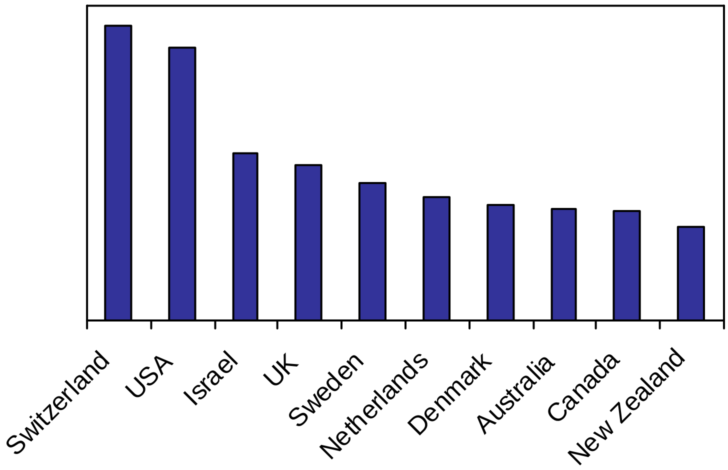
Ranking (41)	*Country*	*Share (total number) of star scientists*
1	USA	66.2% (3,620)
2	UK	7.6% (418)
3	Germany	4.2% (228)
4	Japan	4.0% (218)
5	Canada	3.0% (162)
6	France	2.7% (146)
7	Australia	1.8% (100)
8	Switzerland	1.8% (99)
9	Netherlands	1.6% (90)
10	Italy	1.3% (70)
Other countries (31)		5.8% (321)
Missing		(98)
Total		100% (5,472)

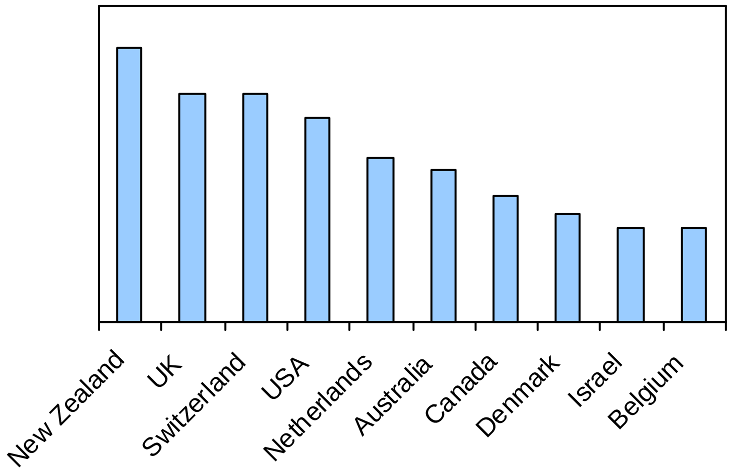
Region	*Share (total number) of star scientists*
USA	66.2% (3,620)
Western Europe	14.9% (814)
UK	7.6% (418)
Japan	4.0% (218)
Canada	3.0% (162)
Oceania	2.1% (117)
Israel	0.9% (47)
China	0.4% (19)
Asia	0.3% (17)
India	0.2% (11)
Other regions (6)	0.2% (8)
Missing	(98)
Total	100% (5,472)

Of course the country ranking also reflects the difference in size between these countries. In relative terms the 1.8% share of a small country like Switzerland may be more relevant than the 66% of the US. Therefore we calculated a relative ranking by standardizing the numbers of star scientists on the basis of number of inhabitants and research expenditures of the respective country (see Figure 3).

The industrialised West is still the prime residence of star scientists in contrast to countries in transition or less developed regions. The overall picture remains the same but the structure of the ranking is different. Although still among the leading countries the US loses its absolute dominance and drops to second and fourth place. Switzerland becomes top and takes first and third rank, which is particularly remarkable. Generally it is noticeable that “big” nations such as Japan, Germany, France and Italy drop out of the ranking whereas “small” nations such as Denmark, Sweden, Belgium and Israel forge ahead in the ranking.

Figure 3: Country ranking in relative terms (above: number of inhabitants as basis; beneath: research expenditure as basis)





In section 2.5 we have mentioned the hypothesis that the mobility of star scientists varies by discipline. As far as their spatial distribution is concerned, we find support for this hypothesis in our dataset. For better comparability we report this part of the analysis on the level of regions (see appendix). A parallel analysis for countries yields qualitatively the same results. A Chi^2 Test of Subject Category by Region indicates a highly significant relationship (Chi^2 = 1,061, DF = 300). We identify those cells in the cross-tabulation which deviate the most (positively and negatively) from their expected values. High positive deviations indicate that the specific region is specialized in the respective research area.

Table 5 shows that 2/3 of all subject categories (14 out of 21) are dominated either by the US or by Western Europe. Note that this dominance is beyond resulting from the strong concentration of star scientists in these regions. The highest positive deviations are indicated by ▲ , the highest negative by ▼. Particularly remarkable is the strong oppositional scientific specialisation of the two regions. Except for two subject categories where both regions are relatively strong (Mathematics; Molecular Biology & Genetics) the US has research strengths in subject categories where Western Europe is weak and vice versa. The US is clearly leading in Clinical Medicine, Computer Science, Economics & Business, Engineering, Psychology & Psychiatry and General Social Sciences. Research areas where Western Europe has a comparative advantage are Agricultural Sciences, Chemistry, Immunology, Microbiology, Pharmacology and Physics.

In the remaining third of subject categories (7 out of 21) the US as well as Western Europe are relatively weak compared to other industrialised regions (see Table 6). The UK has a higher than expected number of star scientists in Neuroscience, Plant & Animal Science, and Space Sciences. Australia and New Zealand (Oceania) take the lead in Ecology & Environment and in Geosciences. Japan is dominating in Biology & Biochemistry and Materials Science.

Table 5: Regional research strengths and weaknesses of the US vs. Western Europe

Research Area (Subject Category)	*USA*	*WE*
Agricultural Sciences	▼	▲
Chemistry	▼	▲
Clinical Medicine	▲	▼
Computer Science	▲	▼
Economics & Business	▲	▼
Engineering	▲	▼
Immunology	▼	▲
Mathematics	▲	▲[2]
Microbiology	▼	▲
Molecular Biology & Genetics	▲	▲
Pharmacology	▼	▲
Physics	▼	▲
Psychology & Psychiatry	▲	▼
Social Sciences, General	▲	▼

Table 6: Regional research strengths of the UK, Oceania and Japan

Research Area (Subject category)	*USA / WE*	*UK*	*Oceania*	*Japan*
Biology & Biochemistry	▼			▲
Ecology & Environment	▼		▲	
Geosciences	▼		▲	
Materials Science	▼			▲
Neuroscience	▼	▲		
Plant & Animal Science	▼	▲		
Space Sciences	▼	▲		

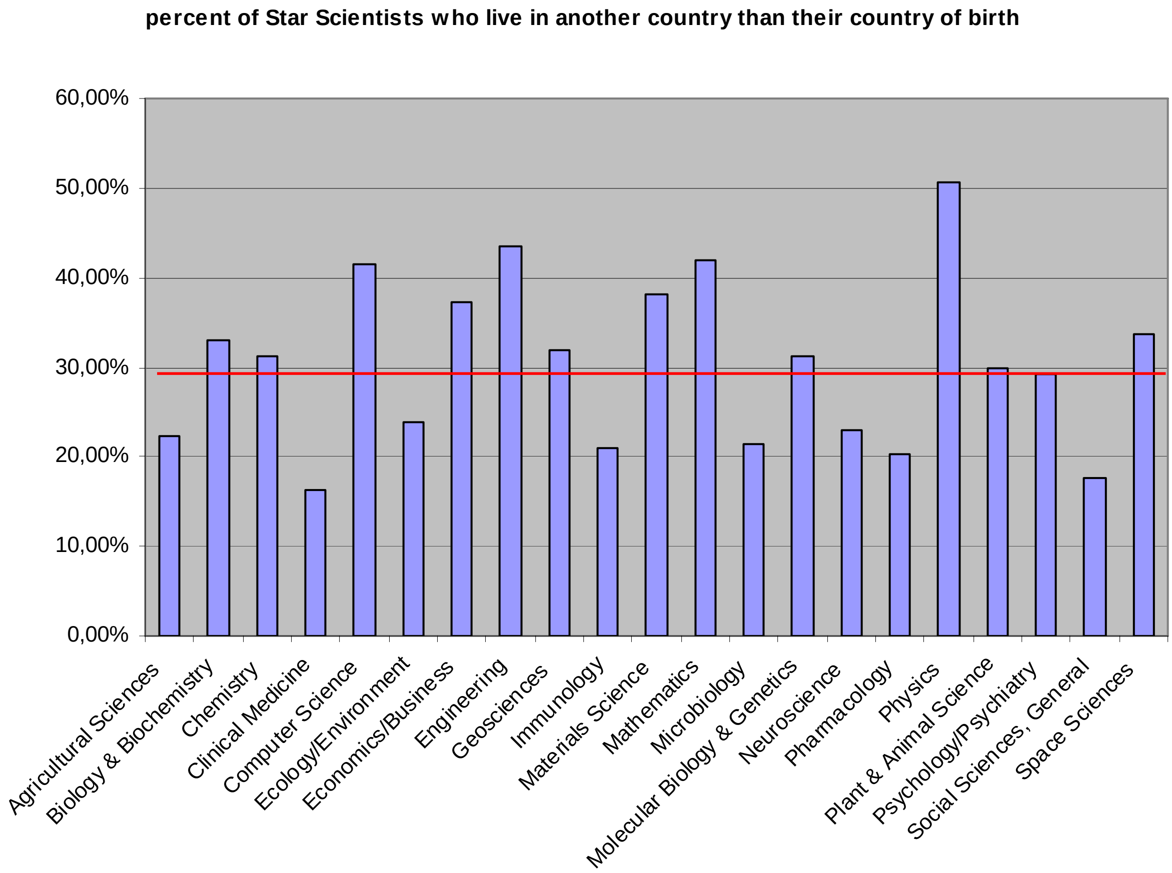
[2] Israel has a stronger position than Western Europe in absolute terms.

3.2.2 Spatial mobility of star scientists – A dynamic view

The observable spatial distribution of star scientists that we have discussed above is in part the result of their interregional or international mobility. Since the available information about educational achievements and positions is of uneven quality, we use a rather narrow definition of mobility and consider those star scientists as mobile whose Country of Birth differs from their current Country. This excludes mobility due to temporary positions, return migration, intermediate changes of residence as well as mobility within a country.

Even based on this rather narrow definition of mobility, 29.5% of all star scientists are mobile, i.e., they live in another country than where they were born. Again, we find significant differences by Subject Category (Chi^2 = 79.3, DF = 20). Most mobile are star scientists in Physics, Engineering, and Computer Sciences, least mobile are those in Clinical Medicine, and Social Sciences (see Figure 4).

Figure 4: Spatial mobility of star scientists according to subject categories



It is safe to assume that this mobility of star scientists is spatially directed. In Table 7 we test this hypothesis by comparing the spatial distributions of star scientists by Country of Birth and Country of Residence. We see that the US is by far the top receiving nation of star scientists. They gain 23.4 percentage points on the expense of all other regions in the world. With -7.1 percentage points Western Europe loses the most, followed by the UK (-3.6%), and Central & Eastern Europe (-2.9%).

Table 7: Worldwide regional migration balances

Region / Country	*Birth*	*Residence*	*Balance*
USA	42.7% (973)	66.2% (3,620)	▲ +23.4%
Western Europe	22.0% (500)	14.9% (814)	▼ -7.1%
UK	11.2% (255)	7.6% (418)	▼ -3.6%
Japan	4.6% (104)	4.0% (218)	-0.6%
Canada	3.0% (68)	3.0% (162)	0.0%
Oceania	3.8% (87)	2.1% (117)	▼ -1.7%
Israel	1.3% (29)	0.9% (47)	-0.4%
China	1.8% (42)	0.4% (19)	▼ -1.4%
Asia	1.1% (25)	0.3% (17)	-0.8%
India	1.8% (40)	0.2% (11)	▼ -1.6%
Central & Eastern Europe	3.1% (71)	0.2% (8)	▼ -2.9%
Central & South America	1.7% (38)	0.2% (8)	▼ -1.5%
South Afria	0.5% (11)	0.1% (6)	-0.4%
Russia	0.5% (11)	0.1% (4)	-0.4%
Middle East	0.6% (13)	0.05% (2)	-0.5%
Africa	0.5% (11)	0.02% (1)	-0.4%
Total	100% (2,278)	100% (5,472)	0.0%

When we look at the Western European countries (see Table 8), we see that not all of them contribute to this loss of talent in the same way. France and Switzerland can increase their shares slightly (0.5% and 0.05% respectively). The highest losses occur in Germany (-1.7%), Italy (-1.6%), the Netherlands (-0.9%), and Austria (-0.7%).

Table 8: Migration balances for Western European countries

Western European Countries	*Birth*	*Residence*	*Balance*
Germany	5.9% (135)	4.2% (228)	▼ -1.7%
France	2.2% (49)	2.7% (146)	▲ +0.5%
Switzerland	1.75% (40)	1.8% (99)	▲ +0.05%
Netherlands	2.5% (56)	1.6% (90)	▼ -0.9%
Italy	2.9% (66)	1.3% (70)	▼ -1.6%
Sweden	1.5% (34)	1% (55)	-0.5%
Belgium	1.2% (27)	0.6% (33)	-0.6%
Denmark	0.6% (14)	0.5% (28)	-0.1%
Spain	0.6% (13)	0.3% (18)	-0.3%
Finland	0.6% (13)	0.2% (13)	-0.4%
Austria	0.9% (20)	0.2% (12)	▼ -0.7%
Norway	0.4% (9)	0.2% (10)	-0.2%
Ireland	0.4% (9)	0.13% (7)	-0.27%
Greece	0.35% (8)	0.07% (4)	-0.28%
Portugal	0.18% (4)	0.02% (1)	-0.16%
Luxembourg	0.09% (2)	0.0% (0)	-0.09%
Cyprus	0.04% (1)	0.0% (0)	-0.04%

Western Europe (total)	22% (500)	14.9% (814)	-7.1%

In the previous analysis we have compared the spatial distributions of star scientists by their country of birth and their country of residence. Since many star scientists have not specified their country of birth, the distribution by country of birth is based on much fewer observations than that by country of residence. For those star scientists who provide information for both variables, we can identify the implied migration flows (Figure 5). The high attraction of the US becomes apparent again. In total 443 expatriate star scientists currently live in the US. They constitute 32% of all star scientists living in the US (Figure 6). The most important sending regions are Western Europe (98), UK (81), Central & Eastern Europe (45), Canada (35), India (33), Oceania (28), China (27) and Central and South America (24). Counter flows of notable size (five or more) occur only with respect to Canada (9), Western Europe (7) and UK (6). Outflows from the US amount to 29 star scientists in total and go to Canada (9), Western Europe (7), UK (6), Oceania (3), Israel (3), and Central & South America (1).

Exporting 81 star scientists to the US, the UK is the most important single country of origin for US expatriate star scientists. In addition the UK loses 15 star scientists to Western Europe while gaining 7 in return and loses another 12 to Oceania. Besides the US, the UK seems to be the only notable hub for internationally mobile star scientists especially regarding English speaking nations.

When we disaggregate the 98 star scientists going from Western Europe to the US by country, we find that Germany (22), Italy (14) and The Netherlands (11) are the most important sources.

Figure 5: Worldwide regional migration flows of star scientists

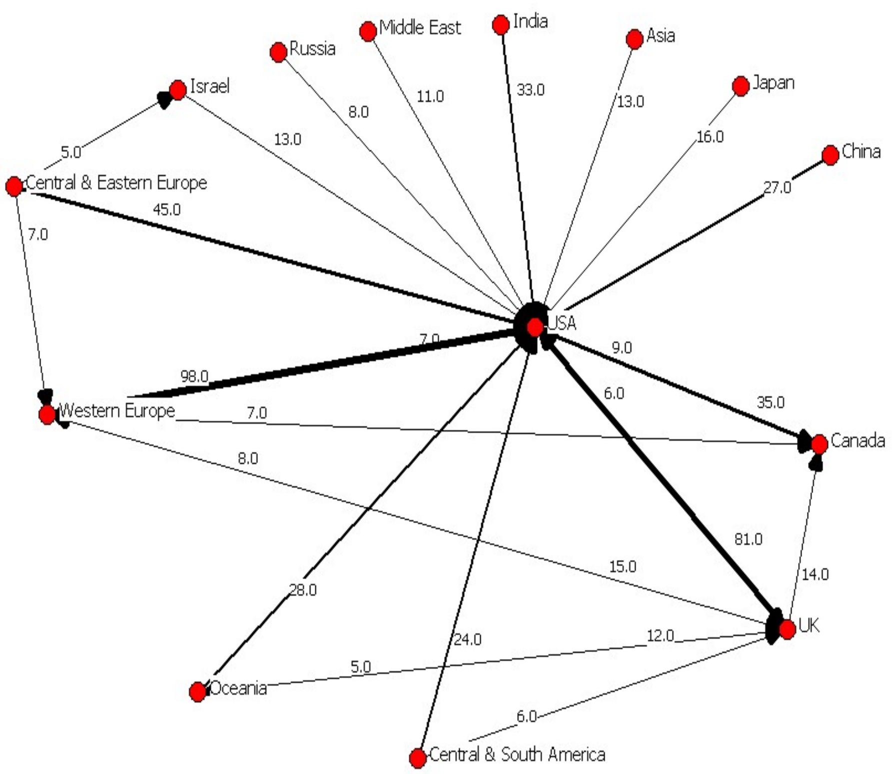
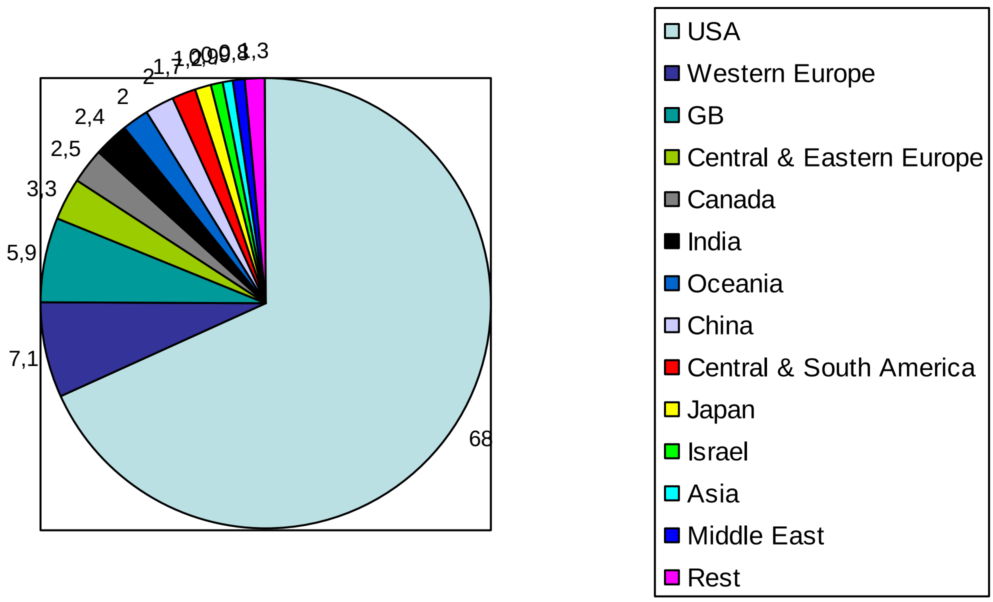


Figure 6: star scientists in the US by country of birth



In Figure 7 we are taking a closer look at Western Europe. The Figure shows the migration links among West European countries. The level of exchange among West European countries is much lower than that among world regions. Only 50 star scientists (out of 378) living in Western Europe were born in another Western European country. Important destinations of migration are Switzerland, France, Germany and The Netherlands. These are also the only countries in Western Europe who gain from internal migration. The most important source of star scientists in Western Europe is Italy which loses 9 persons to other countries without receiving any. At a lower level, Belgium, Finland and Ireland also act as sources. Relatively strong connections exist between Germany, Austria and Switzerland on the one hand, and between Italy and Switzerland on the other. They seem to indicate the importance of language as well as physical and cultural proximity. In Figure 8 the spatial structure of star scientists in Western Europe is shown graphically. We see that 75% of all star scientists in Western Europe come from only 5 countries.

Figure 7: Migration flows within Western Europe

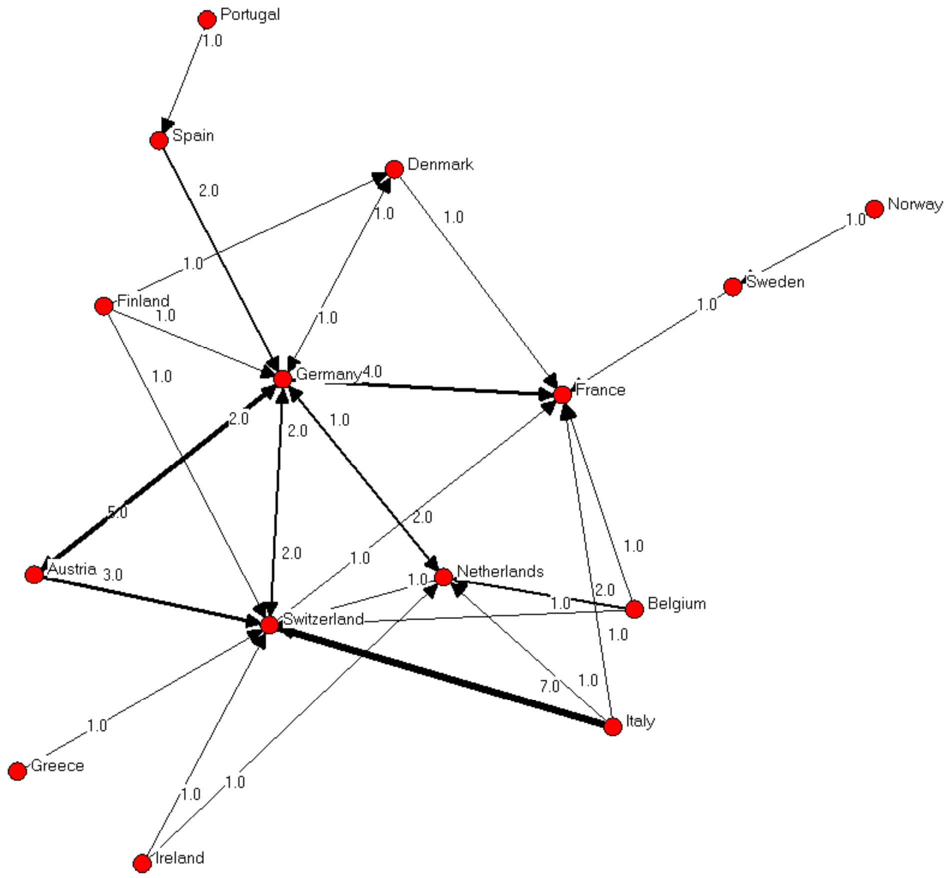
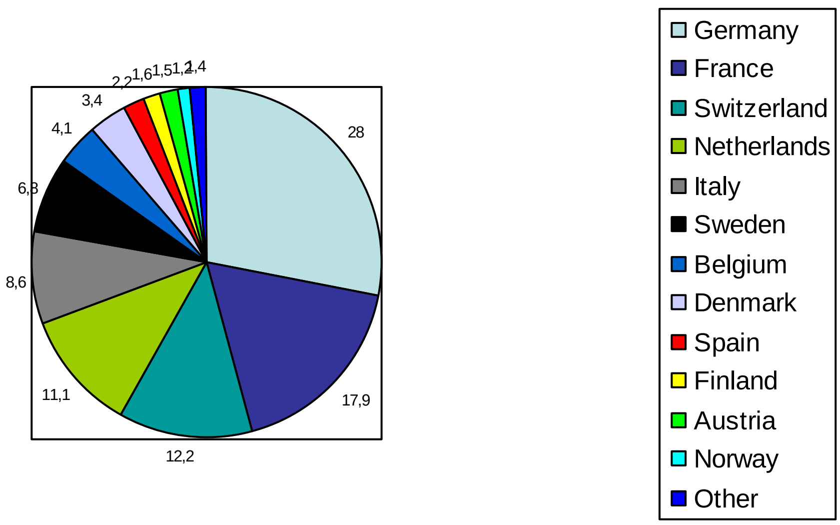
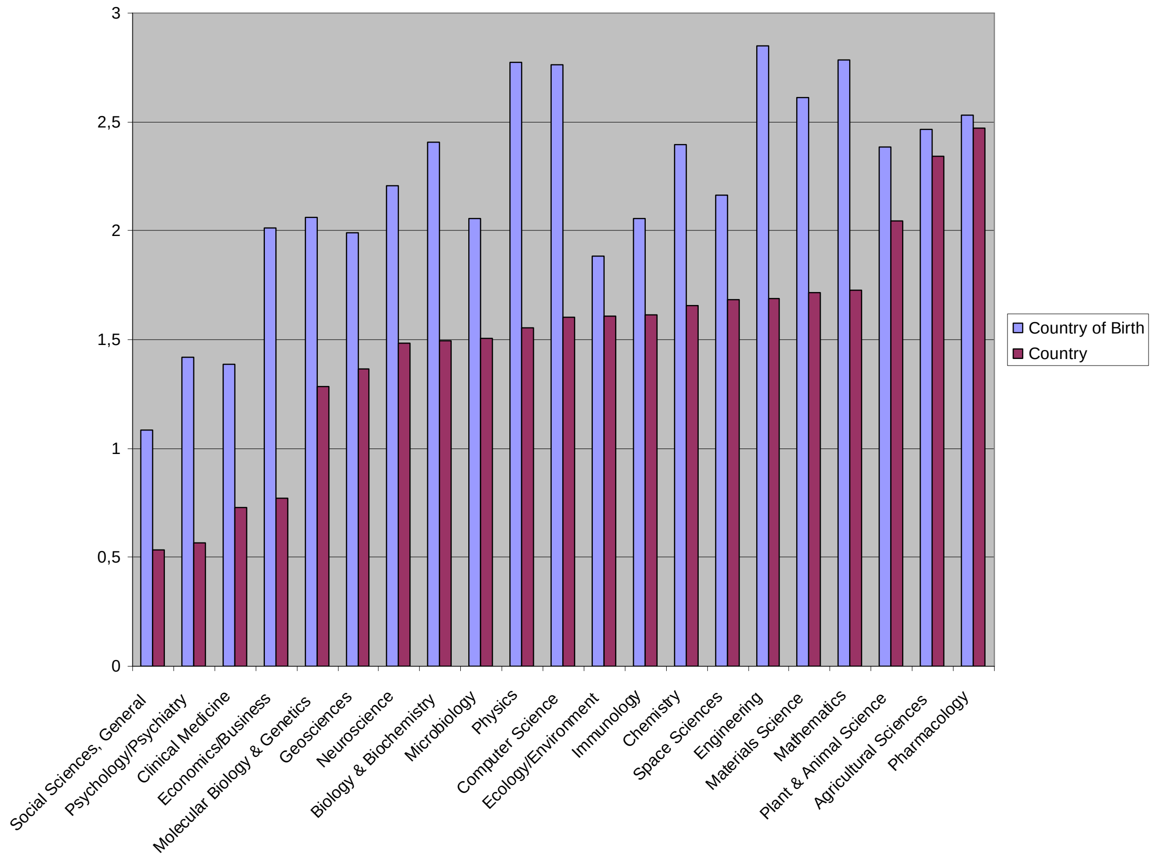


Figure 8: star scientists in Western Europe



The dominant role of the US in the spatial mobility of star scientists that we have observed suggests that it acts toward increasing their spatial concentration. The observed differences by Subject Category also indicate that such a concentration process may differ by discipline and lead to different levels of concentrations depending on the research area. To test this hypothesis, we compute Theil indices[3] for the distribution of star scientists by country of birth and country of residence differentiated by Subject Category. Figure 9 shows the results. Note that smaller bars represent higher levels of spatial concentration.

Figure 9: Spatial concentration and redistribution of star scientists



For the distribution by country of birth the overall Theil index is 2.52, for that by country of residence it is 1.73. This clearly shows that the redistribution of the mobility process leads to a higher level of spatial concentration. This supports our earlier observations and the discussion in the literature: star scientists tend to migrate to countries with an already high concentration of star scientists.

As we see in Figure 9, this observation holds for every one of the Subject Categories. For every Category the Theil index for the Country of Residence is lower than that for the Country of Birth. In some cases, like Economics & Business, the difference is dramatic, in

[3] The Theil index is a distribution measure based upon the entropy concept. When x_i is the percentage distribution of the respective indicator over *n* categories, the Theil index is defined as $I = -\sum_{i=1}^{n} x_i \ln(x_i)$. It is common practice to set the term in the summation to zero for $x_i = 0$. When the whole distribution is concentrated in one category, the index takes on the value zero, when it is evenly distributed over all categories, it is $\ln(n)$.

others, like Pharmacology, it is rather small. Moreover, we see dramatic differences between Subject Categories in the spatial concentration of star scientists. Pharmacology and Agricultural Sciences are the least concentrated Categories and also show only a small increase in concentration due to mobility. Social Sciences and Psychology/Psychiatry on the other hand are most concentrated. They also show a strong concentration tendency due to mobility.

When we compare these results with those about the mobility by Subject Category (Figure 4), we see that the most mobile Categories (Physics, Mathematics, Engineering, Computer Sciences, Material Sciences, Economics/Business) also are the ones with the largest absolute decline in the Theil index between birth and residence. This supports the interpretation that spatial mobility of star scientists leads to more spatial concentration.

3.2.3 Mobility and Education

An important aspect in connection with the mobility of highly qualified people is the distributional one: who invested into the qualification of these people and who enjoys the benefit of the investment. Since we have information about educational attainments of a number of the star scientists in our dataset, we can shed some light on this question. Since the star scientists applied quite different standards when reporting educational attainments, we utilize only the implied information about mobility.

Of the 2,218 star scientists who supply educational information and inform about their country of birth and country of residence, 72.4% received all their education from a single country. For 90.4% of them that country is identical with their country of birth. Thus they were not internationally mobile for educational purposes. For 1,226 of them the country of residence is also identical to the country of birth. Nearly 60% these star scientists are from the US, 9.3% from the UK. Other larger contributions are from Japan (6.2%) and Germany (6.0%).

We can get some weak hint concerning return migration of star scientists by looking at the educational attainments of those who live in their country of birth (1,559 persons). As mentioned above, 1,226 (78.6%) of them also got all their education from the same country. This implies that 333 (21.4%) of them were mobile for educational purposes and received at least part of their education abroad. When we compare this with the number of star scientists who received some of their education abroad (767), we see that only 43.4% of them now live in their country of birth while 56.6% of them stayed abroad. This indicates the great importance of educational mobility for the location of star scientists.

In most cases the star scientists received at least some of their education from their home country. For the 621 persons who provide all the necessary information and who live in another country than their country of birth, we analyzed whether their country of birth and/or their country of residence is among the sources of their education. The results are shown in Table 9. When the country of birth is not among the countries from where they received education, we concluded that this person migrated before entering education (BEFORE). When the country of residence is not among the sources of education, we concluded that this person made the final move after concluding education (AFTER). When both, country of birth and country of residence are among their sources of education, we conclude that the person has migrated during the process of education (DURING). In the last two cases, the country of birth provided at least part of the education for the star scientist. This is the case for 74.2% of the star scientists in the dataset.

There may be substantial differences in the timing of migration by country of birth. We again tested this hypothesis with a Chi^2 Test and found a significant relationship (Chi^2 = 89.4; DF = 20). Countries like China and Germany lost higher than proportional numbers of star scientists in the BEFORE category, New Zealand and UK mainly lost them after they have received their education (Table 9).

Table 9: Mobility and academic education of star scientists

Home Country	***Before***	***During***	***After***
UK	10.81%	21.62%	67.57%
Canada	11.43%	57.14%	31.43%
India	18.18%	57.58%	24.24%
China	61.54%	34.62%	3.85%
Germany	45.45%	18.18%	36.36%
Australia	0.00%	47.06%	52.94%
Japan	18.75%	37.50%	43.75%
Italy	14.29%	35.71%	50.00%
Israel	8.33%	58.33%	33.33%
Netherlands	27.27%	27.27%	45.45%
New Zealand	0.00%	10.00%	90.00%

	Persons	Percent
BEFORE	160	25.76%
DURING	178	28.66%
AFTER	283	45.57%
ALL	621	100.00%

4 Summary and Conclusions

In this paper we looked at the role of knowledge spillover agents in the development of regions, both from a theoretical and an empirical point of view. While the theoretical section reviews the relevant literature from a rather broad perspective, the empirical analysis concentrates on the geographical distribution and the spatial mobility of star scientists, where the latter are operationalized by the highly cited researchers identified in *ISI HighlyCited.com.*

The theoretical discussion in Section 2 of the paper reviews the key insights about the relationship between skilled labour, their knowledge and mobility, and the development of regions. The section demonstrates the particular relevance of highly skilled labour for regional development and argues that major parts of their most valuable knowledge are embodied in the individuals and remain tacit. However, it turns out that spatially mobile knowledge spillover agents may generate a number of side effects that lead to a more complex picture than the simple brain drain – brain gain dichotomy. The term brain circulation seems to be more adequate for describing the effects of the mobility of knowledge spillover agents.

The empirical analysis in section 3 focusses on highly cited “star scientists” as identified by *ISI HighlyCited.com*. This dataset allows us to look closely into the spatial distribution of these highly qualified individuals, and major aspects of their mobility patterns. Among them is the role played by education. As it turns out, the major empirical result of the analysis is the strong concentration of star scientists in the highly industrialized countries and in the US in particular. We find significant differences between subject categories regarding mobility and spatial concentration. Since mobility patterns are strongly oriented toward the US, they contribute to an increase in the spatial concentration of star scientists in all subject categories.

The Western European countries are by far the most important source of star scientists moving to the US. Within Western Europe the mobility patterns are less strong and less clearly directed. Education seems to be an important element also for the mobility of talent. Star Scientists who leave their home country for educational purposes are unlikely to return back home, while those who stay for their education are more likely to remain in their country of birth.

A few caveats are in order here which should be eliminated by further research.

1. Researchers are not born as a star scientist but become one in their careers through talent, accumulated knowledge, external support, provided opportunities, etc. Their location or mobility may be the key requirement for becoming a star. The empirical results of our analysis which seem to show a brain drain from all regions of the world to the US may therefore also be interpreted as the outcome of superior opportunities in the US for becoming a star scientist.
2. The dataset takes into account only publications up to 2002 and therefore does not reflect most recent developments. Moreover, because of the definition of a star scientist that is implied in the dataset, the results are dominated by older researchers. This effect is particularly strong in certain disciplines like Chemistry and Physics.

Keeping in mind these constraints, however, the empirical analysis of our paper shows that the dataset provides very interesting insights into the spatial aspects of knowledge transfer and into the mechanisms of research excellence. In our view, these preliminary results call for additional empirical research in order to better cover all the aspects that were laid out in the theoretical section of the paper.

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Appendix: Definition of regions

- **Western Europe:** Austria, Belgium, Cyprus, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland
- **Central & Eastern Europe:** Bulgaria, Czech Republic, Estonia, Hungary, Latria, Lithuania, Poland, Romania, Slovakia, Slovenia, Turkey, Ucraine, Yugoslavia
- **Central & South America:** Argentina, Brazil, Chile, Colombia, Cuba, Dutch West Indies, Guyana, Honduras, Mexico, Panama, Peru, Trinidad, Uruguay, Venezuela
- **Africa:** Algeria, Congo (DRC), Kenya, Mauritius, Morocco, Nigeria, Tunisia, Zimbabwe
- **China:** China (Mainland), China (Hong Kong)
- **Asia:** Korea (ROK), Malaysia, Philippines, Singapore, Taiwan, Vietnam, Sri Lanka
- **Oceania:** Australia, New Zealand
- **Middle East:** Egypt, Iran, Lebanon, Pakistan, Saudi Arabia

single country regions

- **United Kingdom**
- **South Africa**
- **Israel**
- **United States**
- **Canada**
- **Russia**
- **India**
- **Japan**