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SRE-Discussion 2009/06 2009

R U W
Regional- und Umweltwirtschaft

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October 2009

Acknowledgements: I am grateful to my colleagues Gunther Maier and Ed Bergman from Vienna University of Economics and Business (Austria) for useful suggestions. My special thanks go to Uli Hilpert from the Friedrich-Schiller-University, Jena (Germany) for many valuable and insightful comments on earlier versions of this paper. The usual disclaimers apply.

Abstract

Top researchers and outstanding scientists are an essential source of science-based innovation and regional development. The location pattern and international movements of the scientific elite, are, thus, of fundamental importance. However, despite a growing interest, there is only little empirical evidence about these core issues. Drawing on the results of a world-wide survey of 720 "star scientists" (identified by the number of citations they generated in journals in the ISI databases in the period 1981-2002) this paper seeks to explore the role of islands of innovation in providing employment opportunities for stars. It is shown that US and European islands of innovation and their regional labor markets are at the forefront when it comes to produce (i.e. to educate) and to employ star scientists and to exchange them with other places. Furthermore, the paper provides evidence for the formation of a network among innovative regional labor markets based on international movements of the best and brightest scientific minds.

Keywords: islands of innovation, innovative regional labor markets, star scientists, scientific mobility

JEL classification: J61, O30, R10

1 Introduction

There is a growing awareness in both academic and policy circles that highly qualified scientists and top researchers are crucial drivers of regional high-tech development and science-based innovation (HOROWITZ, 1966; THORN and HOLM-NIELSEN, 2008; TRIPPL, 2009). Star scientists make major and exceptional contributions to the advancement of science and to technological breakthroughs, which can form an essential basis for the emergence and dynamic evolution of new science-based sectors and innovative regional development (ZUCKER et al., 2002). Given the key role that is potentially played by top scientists in fuelling regional high-tech dynamics, their location pattern and international movements are issues of essential importance. The literature suggests that the scientific elite is highly mobile (MEYER et al., 2001) and tends to concentrate geographically in only a few places worldwide (MAHROUM, 2003; LAUDEL, 2005; ZUCKER and DARBY, 2007). Despite an increasing interest in these issues, empirical evidence about the spatial movements of the best and brightest scientists remains scarce (see also LAUDEL, 2005). Furthermore, apart from a few notable exceptions (see, for instance, ZUCKER and DARBY, 2007) only few attempts have been made so far to identify those regions where the scientific elite can be met.

This paper seeks to examine which regions are characterized by innovative labor markets that empower them to be at the forefront when it comes to "produce" (i.e. to educate) and employ star scientists and to exchange them with other places. This enables one to identify those regions which have good chances to be amongst the areas, where future science-based innovation might occur, because they possess a key ingredient for such processes, that is, world-class researchers. Arguably, star scientists can be expected to work at particular places only, when appropriate jobs and favorable working conditions are available. Consequently, specific labor markets offering such jobs seem to be required to attract and retain star scientists. Since stars indicate a propensity to be internationally mobile, it can be assumed that they move in particular between such places, giving rise to the formation and reproduction of a network between innovative labor markets.

This paper investigates the role of labor markets of regional "islands of innovation" (HILPERT, 1992, 2009) in the United States and Europe in providing employment opportunities for "star scientists". The motivation for doing so is that these islands of innovation have been identified as advanced centers of industrial and scientific expertise (see in particular HILPERT, 1992). There are strong reasons to assume that these regions and their innovative labor markets offer superior working conditions and are, thus, highly attractive for star scientists. Star scientists are referred to here as outstanding academics and researchers who have made major contributions to the advancement of science and technology in recent decades. These stars are identified by the number of citations they generated in journals in the ISI databases in the period 1981 to 2001. Using data from a worldwide survey of 720 star scientists, the role of islands of innovation in providing education and employment opportunities for these outstanding individuals will be investigated. Furthermore, international movements of star scientists will be tracked to explore the degree of networking between innovative labor markets. More specifically, this article deals with the following research questions:

- To what extent are star scientists spatially concentrated in US and European islands of innovation and what is the role of these regions in educating and attracting internationally mobile members of the scientific elite?

- What is the geography of international movements of the best and brightest scientific minds in the world? Do the members of the scientific elite mainly move between islands of innovation, thus contributing to the networking and exchange of expertise among the labor markets of islands of innovation?

The remainder of this paper is organized in four sections. Section 2 examines in more detail the role of star scientists in regional development and provides a short literature review on scientific mobility and islands of innovation. Section 3 describes the data of the study and contains some methodological notes. Results on the location and education of star scientists in islands of innovation and flows of stars to and from these advanced regional centers are presented in section 4. The final section summarizes the key results of the paper and draws some conclusions.

2 Star Scientists, Regional Development and Islands of Innovation: A Literature Review

There is an increasing recognition in both the academic literature and in the policy community that top researchers and highly qualified scientists play a central role in innovation and regional growth (HOROWITZ, 1966; ZUCKER et al., 2002; FURUKAWA and GOTO, 2006; THORN and HOLM-NIELSEN, 2008; BABA et al., 2009; TRIPPL 2009). Regional development is considered to depend critically on the provision of employment opportunities for star scientists. Star scientists represent a small but decisive and highly influential group of the research community. They are among the very best and brightest researchers in the world. In elucidating the impact of the scientific elite one has to take into account the multifarious role that is performed by these outstanding individuals. Star scientists are not only a source of creative power in science but also an essential economic asset, spurring regional development. The literature suggests that the scientific elite is an essential element of the strength of a region's and nation's science base (LAUDEL, 2005). Star scientists are acknowledged to be carriers of unique cutting-edge knowledge and they make major and exceptional contributions to the advancement of science and technology. Furthermore, it is argued that their reputation attracts the best young talents (MULKAY, 1976; ZUCKERMAN, 1977; LAUDEL, 2005). Elite members, thus, generate the new elites, leading to a further strengthening of the regional science base. The excellence of star scientists, however, is often far from being limited to academia.

Employment of such outstanding scientists can potentially contribute to regional development and innovation. This might hold in particular true for science-based industries (PAVITT, 1984) or sectors with an analytical knowledge base (ASHEIM and GERTLER, 2005; COOKE et al., 2007) which rely heavily on scientific knowledge inputs during the innovation process. BABA et al. (2009) have recently shown that collaborations with top researchers have a positive effect on the innovative performance of firms operating in the advanced materials fields. Zucker and her colleagues provided evidence that in the rapidly advancing science and technology area of biotechnology star scientists play an important role, influencing the use of the new technology by firms (ZUCKER et al., 1998, 2002). In these studies direct involvement of star scientists proved to be a major factor in determining which firms were ultimately major winners in biotechnology. In another paper ZUCKER and DARBY (2006) explored the role of the scientific elite in all areas of science and technology. They demonstrated that the number of stars employed in a US 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. These findings led 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, emphasizing 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. This view is supported by TRIPPL (2009) who has recently shown that star scientists are often involved in knowledge sharing activities that can potentially contribute to regional development and innovation. TRIPPL (2009) found that stars tend to embed themselves in their current location of work by creating multiple forms of knowledge linkages to regional firms, research institutes and policy actors. Furthermore, in the same study it was demonstrated that those star scientists who have an international mobility background often retain their ties to their previous research location, thus connecting their current host region to global centers of excellence.

Given the importance of these extraordinarily individuals for both scientific progress and regional development, their location pattern of employment and their movements to specific places matter fundamentally. Generally, scientists and researchers tend to be highly mobile at an international level (MEYER et al., 2001; ACKERS and GILL, 2008). The literature suggests that there are enormous imbalances in the geography of such flows, resulting in an uneven distribution of scientific capabilities and innovative regional labor markets. Generally, the United States seem to benefit rather strongly from the inflow of top researchers from abroad. STEPHAN and LEVIN (2001) have shown in a comprehensive study that foreign-born and foreign-educated highly skilled talents are disproportionately represented among individuals making outstanding contributions to science and engineering in the United States, and are, thus, a key source of strength and vitality for US science. SAXENIAN (1999) provided evidence that foreign-born scientists and immigrant engineers account for a significant and growing proportions of Silicon Valley's workforce and are also an essential source of new firm formation in this region. After studying and working in Silicon Valley, some of these skilled immigrants return to their home countries to take advantage of new job opportunities offered there, setting off a process of international brain circulation (SAXENIAN, 2005).

For the group of star scientists it is often argued in the literature that they tend to go where the best facilities are, i.e. they are attracted by global centers of excellence and the presence of other outstanding researchers (MAHROUM, 2003; ZUCKER and DARBY, 2007). Star scientists concentrate geographically in only a few places worldwide (MAHROUM, 2003; LAUDEL, 2005). This implies that it is only a limited number of regions that provide an appropriate labor market and can, thus, take advantage of the excellence and often scarce and to some extent tacit knowledge embodied in star scientists.

This paper investigates as to what extent islands of innovation because of their innovative labor markets represent the key location of choice for star scientists. According to HILPERT (1992) islands of innovation are essential nuclei of science-based innovation, attracting a high share of public R&D expenditures and hosting not only many excellent research institutions but also many enterprises with strong capacities to make use of the scientific knowledge available in the region. Consequently, islands of innovation are identified by the co-existence of scientific and industrial expertise. HILPERT (1992) has shown that it is only a few places in the United States and in Europe which are characterized by such unique conditions and could, thus, be classified as islands of innovation. Importantly, this phenomenon seems to be

rather stable over time. Although some framework conditions have changed considerably in the last years, today it is still the same regions which perform as islands of innovation (HILPERT, 2009). Their strong role as core centers of science-based innovation continued rather unaltered over a quarter of a century. This is also reflected in the outstanding position taken by these regions in international scientific and industrial collaborations. Islands of innovation act as key nodes in such international networks and they are often strongly connected to each other via scientific and industrial co-operative linkages (HILPERT, 2009).

There are good reasons to assume that these islands of innovation are highly attractive for star scientists. Their innovative labor markets and strengths in both scientific and industrial capabilities constitute an environment that is conducive for scientific breakthroughs and provides top researchers with attractive conditions to apply their knowledge. In section 4 it will be examined whether or not the US and European islands of innovation as they have been identified by HILPERT (1992, 2009) are favorite working places for the best and brightest scientists. Additionally, for the United State information from the Association of American Universities (AAU) was used. AAU provides a list of 60 leading public and private research universities in the United States. Not fewer than 39 of the 60 AAU universities are located in the US islands of innovation. The remaining 21 universities point to the localization of strong scientific capabilities outside the innovation islands. The areas hosting these universities will be also included in the empirical analyses. These US non-islands of innovation with top universities and will be referred to as "research cities".

3 Data and Methodology

The empirical results reported in this paper stem from a worldwide web-based survey (conducted in August and September 2008) of so called "star scientists", i.e. the world's top and most renowned scientists and research professionals. More precisely, making use of the database "ISI Highly Cited", star scientists are referred to here as authors of highly cited research papers. ISI Highly Cited is an online information service provided by the Institute for Scientific Information (ISI), a subsidiary of Thomson Incorporated. With this freely accessible website (http://isihighlycited.com/) 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 journals in the ISI databases. ISI Highly Cited distinguishes between 21 different areas of research (subject 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 Highly Cited is based on publications and citations from the period 1981-2002.

The database includes approximately 5,600 star scientists, comprising less than 0.5% of all worldwide publishing researchers. All 3,274 star scientists who provide their contact information (e-mail address) in the database have been contacted and invited to fill in the questionnaire. Only 433 of them were not reachable due to invalid e-mail addresses. Out of the remaining 2,841 star scientists, 720 stars returned usable (fully filled in except for single missing values) questionnaires. This corresponds to a response rate of 25.34%.

Table 1 provides an overview on key characteristics of the overall sample. The overwhelming majority of responding star scientists is male (93%) and more than 50% of them are older than 60 years, signaling that they are at a relatively mature stage of their professional careers. A vast majority of the sampled scientists (70%) is employed by universities. About 18% are

working for non-university research institutions, whilst the proportion of star scientists from the corporate sector is negligible (2%). Under the category "other" the respondents have indicated that they are retired, have founded their own company, work for the government, or do non-profit research or consulting. Looking at the subject areas, biology & biochemistry (8.8%), chemistry (8.2%) and ecology & environment (7.4%) are found to represent the most important research disciplines. If the 21 subject categories are classified according to the Frascati Manual (OECD 2006) into broader fields of science and technology, it can be seen that more than 50% of the respondents are working in the field of natural science, and another 23% in medical and health sciences. Other categories (engineering, social science, agricultural science) play a minor role in comparison.

Table 1: Sample Characteristics (% of star scientists)

			Percentages
Gender *(N=720)*	Female		5.6
	Male		92.6
	Missing		1.8
Year of Birth *(N=720)*	Mean:	1946.5	
Type of Institution *(N=720)*	University		70.4
	Non-university research entity		18.3
	Corporate research unit		2.1
	Other		5.8
	Missing		3.3
Research Discipline *(N=720)*	Natural Sciences		53.3
	Agriculture Science		3.1
	Engineering and Technology		10.1
	Medical and Health Sciences		23.3
	Social Sciences		7.6
	Missing		2.5
Mobility Background *(N=720)*	Non-Movers		47.9
	Expatriates		25.1
	Returnees		26.9
Expatriates: Years spent already abroad *(N=181)*	Mean (Min. 0.7, Max. 60):		29.5
	1 – 10 years		11.6
	11 – 20 years		8.8
	21 – 30 years		29.8
	31 – 40 years		30.9
	More than 40 years		16.6
	Missing		2.2
Returnees: Years spent abroad *(N=194)*	Mean (Min. 0.5, Max. 40):		5.9
	Less than 1 year		1.6
	1 – 3 years		49.0
	4 – 10 years		32.5
	More than 10 years		12.9
	Missing		4.1

Finally, data on the mobility background of the surveyed star scientists were collected. Almost 48% of them can be classified as "non-movers", i.e. scientists who have, so far, not relocated internationally for professional purposes, but have stayed in their home countries. Another 52% have an international mobility background. Here a distinction between expatriates on the one hand and returnees on the other hand can be drawn. Expatriates are defined as researchers, who have left their home countries and now live and work at a foreign

location. Their share in the sample is 25%. On average they have already spent 30 years away from home. Returnees (i.e. scientists, who have moved back to their home countries after living abroad for a substantial period of time) represent 27% of all sampled stars. They have spent on average six years abroad, before relocating back home.

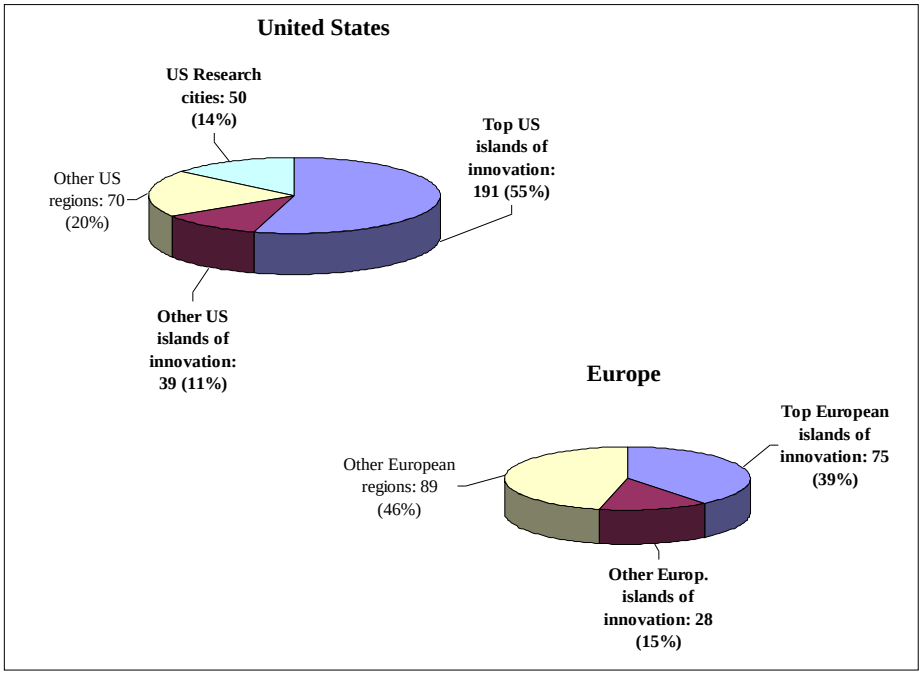
4 Empirical Part: Islands of Innovation and Star Scientists

This section presents important results of the empirical analysis of the location pattern and spatial movements of the surveyed star scientists. As noted above, top researchers and outstanding scientists have the potential to be key drivers of science-based innovation, as their excellence and often scarce and to some extent tacit knowledge could form essential inputs for the rise and dynamic evolution of new industries. Consequently, it is intriguing to explore where the best and brightest researchers in their respective disciplines are located. It enables one to identify those regions, which have good chances to be amongst the places, where future science-based innovation might occur, because they possess a key ingredient for such processes, that is, world-class researchers.

4.1 Islands of Innovation as Location for Star Scientists

The surveyed star scientists are unevenly distributed across space. The United States clearly have the lead, hosting not fewer than 56% of the top researchers included in the sample. Europe accounts for 28% of all star scientists, whilst Asia (7%), Canada (4%), Oceania (4%) and other parts of the world show a rather low capacity to attract or retain top researchers in comparison. Together, the United States and Europe provide employment opportunities for about 85% of all star scientists included in the sample. Taking a closer view on the existing location pattern of stars in these two continents uncovers that the majority of these highly skilled individuals are strongly concentrated in a few places, pointing to an extraordinarily dominating role and attractiveness of islands of innovation and their innovative labor markets.

Figure 1: Spatial concentration of star scientists in the United States and Europe



In the United States, not fewer than 280 top researchers (representing 80% of the scientific elite located in the United States) are working in an island of innovation or in a research city (Figure 1). Also for Europe a high concentration of stars in a few islands of innovation is found, although this phenomenon is less intensive when compared to the United States. This pattern might result from the specific institutional contexts prevailing in these areas. The United States are characterized by a rather homogeneous institutional set-up and a common research area. The European countries, in contrast, differ strongly in terms of language, culture and research systems, leading to a lower degree of intra-European mobility of scientists and a more decentralized distribution of outstanding researchers across the continent. In Europe almost 55% of the surveyed star scientists (a number of 103 top researchers) are employed in an island of innovation (Figure 1). Together the US islands of innovation and research cities and the European islands of innovation host 59.5% of all surveyed stars who provide information about their current working location. Obviously, these few top places have an enormous magnetic power and constitute main agglomeration centers of the scientific elite.

Labor Markets of US Islands of Innovation and research cities

In the United States, there is a clear hierarchy of the core regions. The top eight US islands of innovation provide labor markets for not fewer than 55% of all US based stars. As revealed in Table 2, key locations with a particular high number of star scientists are the New York region (made up of New York, Ithaca and places like Princeton, New Brunswick, Newark etc. in New Jersey), Los Angeles-San Diego, San Francisco Bay Area (covering famous places such as Stanford, Berkeley, etc.), Washington-Baltimore, and Boston (Boston and Cambridge, MA). The other US islands of innovation which include regions such as Ann Arbor, Philadelphia and Seattle account for 39 star scientists (11.1% of the US-based scientific elite). Furthermore, the group of major research cities with their excellent universities provides jobs for 50 star scientists, representing 14.3% of all stars working in the United States. Regions which have not been categorized as island of innovation or research cities do not provide significant employment opportunities for star scientists.

Importantly, this overall pattern that was found for the United States, i.e. the strong role of islands of innovation as core regions of star scientists, is not restricted to a specific scientific field. On the contrary, the islands of innovation are major location of stars working in very different scientific disciplines. This holds in particular true for the top islands of innovation. Although some of these areas seem to be more specialized in a certain research field than other regions (measured by the number of stars active in a specific science field employed in the region), they all provide labor markets for stars from at least four science fields. This finding points to their generally high attractiveness for top researchers and their strong capacity to recruit or retain the best and brightest scholars in various research disciplines.

Table 2: Number of stars employed in US islands of innovation and research cities

United States	Number of stars	Natural Sciences	Medical & Health Sciences	Engineering	Social Sciences	Agriculture	Missing
Top Islands of Innovation							
New York	35	14	10	4	6	0	1
Los Angeles/San Diego	32	13	8	7	2	1	1
San Francisco Bay Area	29	17	4	6	1	1	
Washington/Baltimore	29	13	13	2	1	0	
Boston	21	10	4	1	5	0	1
Dallas/Houston/San Antonio	19	10	4	2	3	0	
Chicago/Milwaukee	14	7	3	2	2	0	
Raleigh Durham (RTP)	12	7	2	2	1	0	
Total Top Islands	**191**	**91**	**48**	**26**	**21**	**2**	**3**
Other Islands of Innovation							
Ann Arbor, MI	8	6	0	1	1	0	
Philadelphia	8	1	3	1	3	0	
Seattle	8	3	4	0	0	0	1
New Haven/Hartford	5	2	2	0	1	0	
Columbus/Cin.	3	2	1	0	0	0	
NY-Upstate Network	3	1	1	1	0	0	
Pittsburgh	2	0	0	0	2	0	
Minneapolis/St. Paul, MN	1	0	0	1	0	0	
Urbana, IL/Lafayette, IN	1	1	0	0	0	0	
Total Other Islands	**39**	**16**	**11**	**4**	**7**	**0**	**1**
Research Cities							
Boulder, CO	8	6	0	1	1	0	
Atlanta, GA	7	3	4	0	0	0	
Charlottesville, VA	6	4	1	1	0	0	
Bloomington, IN	4	3	0	0	1	0	
Madison, WI	4	3	0	1	0	0	
Nashville, TN	4	1	2	1	0	0	
Cleveland, OH	3	0	3	0	0	0	
State College, PA	3	1	0	2	0	0	
Tucson, AZ	3	3	0	0	0	0	
Gainesville	2	0	0	1	1	0	
Providence, RI	2	1	0	0	1	0	
St. Louis, MO	2	1	1	0	0	0	
Ames, IA	1	1	0	0	0	0	
Iowa City, IA	1	0	1	0	0	0	
Total Research Cities	**50**	**27**	**12**	**7**	**4**	**0**	
Total (Islands of Innovation + Research Centers)	**280**	**134**	**71**	**37**	**32**	**2**	**4**
% of all US-based stars	*80*	*74.9*	*82.6*	*90.2*	*88.9*	*66.7*	

Table 3: Number of stars employed in European islands of innovation

Europe	Number of stars	Natual Sciences	Medical & Health Sciences	Engineering	Social Sciences	Agriculture	Missing
Top Islands of Innovation							
London	26	13	9	1	1	2	
East Anglia	12	9	2	0	0	1	
Munich	8	5	3	0	0	0	
Copenhagen	7	3	1	2	1		
Glasgow/Edinburgh	7	3	3	0		1	
Paris (Ile de France)	6	4	0	1			1
Amsterdam/Rotterdam	5	3	2	0			
Milan/Torino	4	2	2	0			
Total Top Islands	**75**	**42**	**22**	**4**	**2**	**4**	**1**
Other Islands of Innovation							
East Midlands	3	2	1	0			
Heidelberg	3	0	1	2			
Madrid	3	3					
Rhein-Ruhr	3	1	0	0	0	2	
Stuttgart	3	2	0	1	0	0	
Bologna (Emilia Romagna)	2	2					
Strasbourg (Alsace)	2	2	0	0	0	0	
Wageningen (Oost-Nederland)	2	2	0	0	0	0	
West Midlands	2	0	1	0	1	0	
Berlin	1	1					
Bordeaux (Aquitaine)	1	1					
Kaiserslautern	1			1			
Lyon-Grenoble (Rhone-Alpes)	1	1					
Napoli (Campania)	1	0		1			
Total Other Islands	**28**	**17**	**3**	**5**	**1**	**2**	
Total all Islands	**103**	**59**	**25**	**9**	**3**	**6**	**1**
% of all European-based stars	*53.6*	*52.2*	*49.1*	*52.9*	*60.0*	*66.7*	

Labor Markets of European Islands of Innovation

Table 3 presents data concerning the regional distribution of star scientists in Europe. The labor markets of top eight European islands of innovation account for almost 40% of all European based stars. Key places are the London region (London and Oxford), East Anglia (Cambridge, Norwich), Munich, Copenhagen and Glasgow-Edinburgh. Outside the islands of innovation, in Europe no major places providing jobs for many stars could be found. Only Zurich in Switzerland (employment of six stars) and Leuven in Belgium (employment of five stars) represent exceptions in this regard.

To summarize, there is an enormous spatial concentration of the investigated top researchers in a few locations in the United States and Europe. It is only a limited number of regions worldwide which perform as islands of innovation. These regions have created a highly innovative labor market, offering significant employment opportunities for star scientists.

4.2 Islands of Innovation and Educational Origins of Star Scientists

Looking at the places where the scientific elite examined here has been educated again highlights a key role of the islands of innovation. The regional distribution of "star production" is given in Table 4. Not less than 82% (or 239 individuals) of all stars scientists who received their education in the United States have studied in an US island of innovation or in a US research city. It is particularly the top US islands New York, Boston, San Francisco Bay Area and Los Angeles/San Diego which appear to be the major centers of star production in the United States. In Europe, the respective share is 52%. Here, a particular strong role of London and East Anglia could be observed. Obviously, the islands of innovation and major research cities do not only provide employment opportunities for the large majority of star scientists worldwide, but they are also key training places of top researchers, offering excellent education opportunities and attracting outstanding young scholars who later become star scientists. Arguably, the educational role of these areas reproduces and further strengthens their capacity to create innovative labor markets.

However, the analysis of the pattern of star production outside the islands of innovation reveals clear continental differences. Whilst in the United States there is limited evidence of star production outside the islands of innovation and research cities (53 stars or 18%), in Europe the non-islands of innovation account for 48% of star production. This might again reflect rather strong national differences between European countries regarding their science and education systems, culture and language, leading to a lower mobility of students for educational purposes.

Table 4: Education of star scientists in US and European islands of innovation

United States	Number of stars	Europe	Number of stars
Top US islands		**Top European islands**	
New York	39	London	36
Boston	37	East Anglia	20
San Francisco Bay Area	28	Glasgow/Edinburgh	8
Los Angeles/San Diego	19	Munich	8
Ann Arbor, MI	14	Paris (Ile de France)	8
Chicago/Milwaukee	12	Copenhagen	5
Washington/Baltimore	12	Madrid	4
New Haven/Hartford	10	Bologna (Emilia Romagna)	3
Dallas/Houston/San Antonio	7	Milan/Torino	3
Raleigh Durham (RTP)	7	Total Top Islands	95
Total Top Islands	185		
Other US Islands	16	Other European islands	12
US Research Cities	38	**Total all European Islands**	**107**
Total all US Islands + US Research Cities	**239**		
Other US regions	53	Other European regions	99
Total US	**292**	**Total Europe**	**206**
Total US (including 54 stars who provide information about their educational origins at the national level but not at the regional level)	345	Total Europe (including 31 stars who provide information about their educational origins at the national level but not at the regional level)	237

In a next step, it is intriguing to analyze in more detail the educational origins of star scientists who currently work in the top US and European islands of innovation. Table 5 reveals the respective pattern for the top places in the United States. Here, about 18% of star scientists (still or again) work in the innovation island where they received their training. Some regions are clearly above this average number, such as Boston (38% of stars working there have also been educated there), New York (23%), Chicago/Milwaukee (21%), whilst others rely heavily on stars educated elsewhere, like Raleigh Durham and Washington/Baltimore. Another 35% have received their PhD in another US island of innovation. This type of relationship – i.e. the movement of stars who have been educated in one island of innovation to another island of innovation to take a job there – is the most important one found for the United States. Only a small share of stars located in these US islands of innovation received their doctoral training abroad.

Table 5: Educational origins of star scientists located in the top US islands of innovation

	Number of stars working in each region	Places of Education						
		Endo-gamy	Other US islands	US Res. Cities	Rest US	Europ. Islands	Rest Europe	Rest World
Top Islands of Innovation								
New York	35	8	12	2	5	2	2	4
Los Angeles/San Diego	32	5	16	2	5	2	-	2
San Francisco Bay Area	29	4	10	2	4	4	2	3
Washington/Baltimore	29	3	12	2	7	2	-	3
Boston	21	8	4	1	3	2	3	-
Dallas/Houston/San Antonio	19	4	4	2	3	1	1	4
Chicago/Milwaukee	14	3	4	0	1	1	1	4
Raleigh Durham (RTP)	12	0	5	2	3	-	1	1
Total Top Islands	**191**	**35**	**67**	**13**	**31**	**14**	**10**	**21**
(in %)	*(100)*	*(18.3)*	*(35.1)*	*(6.8)*	*(16.2)*	*(7.3)*	*(5.2)*	*(11.0)*

The share of "own production" (endogamy) is much higher in Europe than it is in the US (35% in Europe compared to 18% in the United States). It is particularly high in Copenhagen (57%), Milan/Torino (50%), and Glasgow/Edinburgh (43%), whilst it is below average in East Anglia (25%) and Amsterdam-Rotterdam (20%). From other European islands of innovation 21% have been attracted and another 31% from other European Regions. Only 8% of stars who work in a top European island have been educated in the United States (Table 6).

Table 6: Educational origins of star scientists located in the top European islands of innovation

		Places of Education						
	Number of stars	Endo-gamy	US islands	US Res. Cities	Rest US	Europ. Islands	Rest Europe	Rest World
Top European Islands								
London	26	8	1	-	-	7	8	2
East Anglia	12	3	1	-	-	2	5	1
Munich	8	3	1	-	-	2	1	1
Copenhagen	7	4	1	-	-	-	2	-
Glasgow/Edinburgh	7	3	1	-	-	3	-	-
Paris (Ile de France)	6	2	1	-	-	1	2	-
Amsterdam/Rotterdam	5	1	-	-	-	1	3	-
Milan/Torino	4	2	-	-	-	-	2	-
Total Top European Islands	**75**	**26**	**6**	**-**	**-**	**16**	**23**	**4**
(in %)	*(100)*	*(34.7)*	*(8.0)*	-	-	*(21.3)*	*(30.7)*	*(5.3)*

5 International Movements of Star Scientists and Linkages between Innovative Labor Markets

The evidence provided so far in this article clearly points to a pronounced concentration of star scientists in a few regional labor markets worldwide. Areas that provide such innovative labor markets for the elite researchers possess a critical ingredient for future science-based innovation and they might represent key nodes in international networks between regional labor markets via mobility of top researchers. Arguably, only those regions which host star scientists can take part in the global exchange of these stars, performing as core centers in the international process of scientific brain circulation. In the following the importance of islands of innovation for attracting and retaining different types of star scientists is explored. Looking at the international mobility background of the surveyed top researchers, a distinction between "non-movers", "expatriates" and "returnees" is drawn (see also section 3). Furthermore, this section examines the role of islands of innovation as "sending regions" of expatriates and returnees and it investigate linkages between innovative labor markets.

Islands of Innovation as Sticky Places for Non-Movers and Key Destinations of Internationally Mobile Star Scientists

Which types of star scientists could be found in the islands of innovation in the United States and Europe? Figure 2 and Tables 7 and 8 reveal interesting differences in this context between these two continents. Not less than 58% of all stars working in the US islands of innovation and research centers can be classified as non-movers. This might reflect the superior working conditions for top researchers in the United States, implying that stars are not forced to move away. At the same time these areas seem to be highly attractive for expatriates. More than 30% of the surveyed stars employed in this top regions fall in this category. The share of returnees (11%) is comparatively low.

Figure 2: Types of star scientists located in US and European islands of innovation

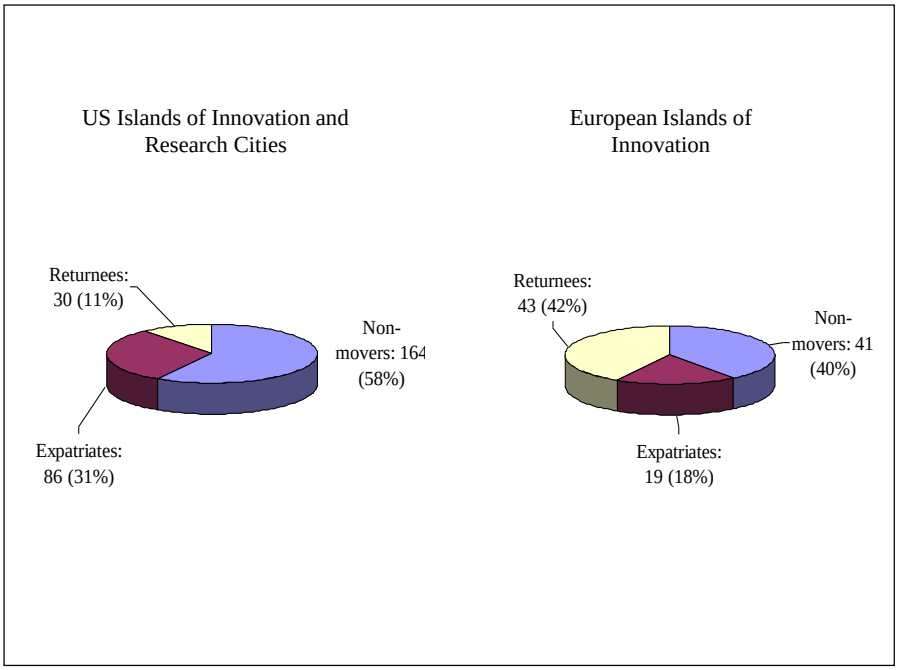


Table 7 provides further details about the types of stars working in the top US islands of innovation. There are some interesting variations between the areas belonging to this group of places. Some regions have an extremely high share of non-movers, whilst others rely more on the inflow of internationally mobile star scientists. "Centers of non-movers" are in particular Washington/Baltimore (82.8%), Los Angeles/San Diego (65.6%) and Dallas (63.2%). Regions with a high share of internationally mobile stars include Chicago/Milwaukee (57.1%) and San Francisco Bay area (55.2%). In the European islands of innovation the situation is clearly different. Only 40% of all those stars who are employed in these areas represent non-movers, whilst 19% could be classified as expatriates (Figure 2). The most important type of star working in the European islands of innovation is the group of returnees (42%). Thus, the top regions in Europe are quite successful in luring their best and brightest scientists back home. Among the leading European islands of innovation it is only the London Region and Milan/Torino, where the share of non-movers is 50%. There are, thus, clear differences between US and European islands of innovation, concerning the type of star scientists they host.

Outflow of Mobile Star Scientists from Islands of Innovation

Generally, the islands of innovation investigated here do not only provide significant employment opportunities for non-movers and expatriates, but they are also essential sending regions of mobile star scientists. However, this statement needs a refinement. Looking at the US islands of innovation, hardly any outflow of US star scientists (i.e. US expatriates) could be observed. It is only 11 star scientists, who have left the US islands of innovation and research cities and now work and live abroad. This finding might reflect the superiority of the labor markets of these areas, implying that outstanding scientists are not forced to move abroad.

Table 7: US islands of innovation: inflow and outflow of mobile stars

			Inflow of internationally mobile stars			Outflow of internationally mobile stars		
	Total	Non-movers	Expat.	Return.	Total gain	Expat.	Return.	Total loss
Top US Islands of Innovation								
New York	35	19	13	3	16	3	13	16
Los Angeles/San Diego	32	21	9	2	11	1	8	9
San Francisco Bay Area	29	13	12	4	16	1	17	18
Washington/Baltimore	29	24	2	3	5	1	8	9
Boston	21	12	8	1	9	1	7	8
Dallas/Houston/San Antonio	19	12	5	2	7	-	1	1
Chicago/Milwaukee	14	6	6	2	8	-	4	4
Raleigh Durham (RTP)	12	7	3	2	5	-	-	-
Total top US islands	**191**	**114**	**58**	**19**	**77**	**7**	**58**	**65**
Other US islands	**39**	**21**	**12**	**6**	**18**	**2**	**7**	**9**
US research cities	**50**	**29**	**16**	**5**	**21**	**2**	**5**	**7**
Total US islands and US research cities	**280**	**164**	**86**	**30**	**116**	**11**	**70**	**81**
Total United States	**390**	**232**	**110**	**48**	**158**	**13**	**87**	**100**

However, as revealed in Table 7, the US islands of innovation and research cities have lost 70 foreign star scientists who relocated back home after working for a while in these areas. Obviously, the US islands of innovation are strong in attracting this type of mobile scientists, but they could not retain them.

In the European islands of innovation a different pattern is found (Table 8). These regions have lost by far more expatriates (a number of 34) than the US islands of innovation. Furthermore, the European islands of innovation experienced an outflow of 26 foreign researchers who have returned to their home regions (returnees).

Table 8: European islands of innovation: inflow and outflow of stars

			Inflow of internationally mobile star scientists			Outflow of internationally mobile scientists		
	Total	Non-movers	Expat.	Return.	Total gain	Expat.	Return.	Total loss
Top European Islands								
London	26	13	6	7	13	17	7	24
East Anglia	12	4	2	6	8	4	4	8
Munich	8	2	1	5	6	3	1	4
Copenhagen	7	2	1	4	5	2	3	5
Glasgow/Edinburgh	7	3	1	3	4	-	1	1
Paris (Ile de France)	6	2	2	2	4	4	1	5
Amsterdam/Rotterdam	5	2	3	0	3	-	2	2
Milan/Torino	4	2	-	2	2	1	-	1
Total Top European Islands	**75**	**30**	**16**	**29**	**45**	**31**	**19**	**50**
Other Islands of Innovation	**28**	**11**	**3**	**14**	**17**	**3**	**7**	**10**
Total all European islands	**103**	**41**	**19**	**43**	**62**	**34**	**26**	**60**
Total Europe	**197**	**69**	**40**	**88**		**99**	**54**	**153**

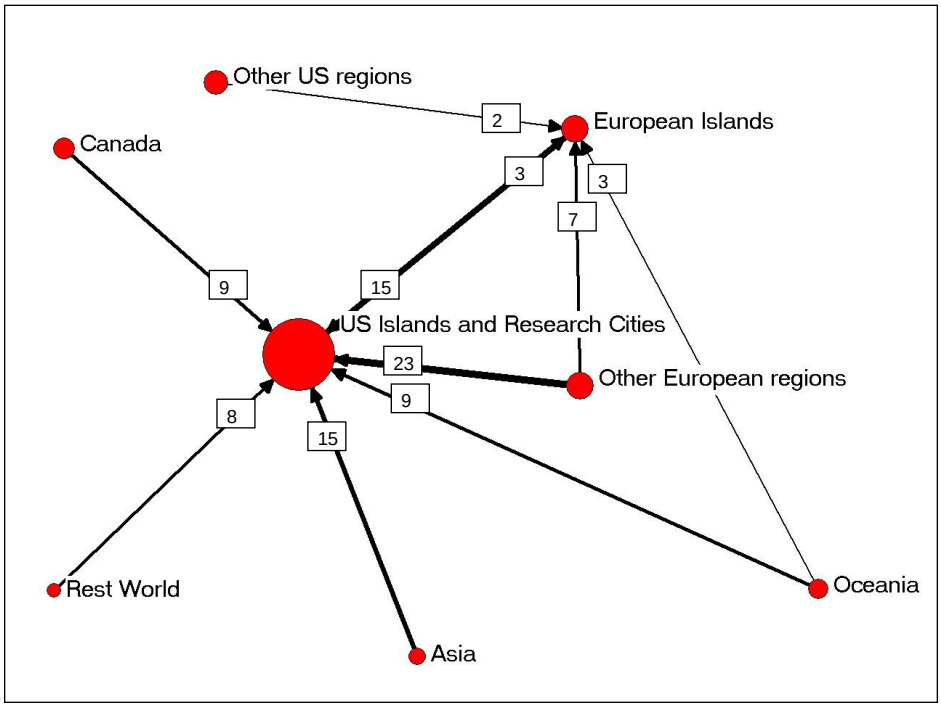
Linkages between Innovative Labor Markets through Movements of Star Scientists

The next step of the analysis is to examine international movements of star scientists and the resulting pattern of linkages between the islands of innovation and their ties with other regions of the world. Given the pronounced differences between expatriates and returnees in terms of the period of time they have (already) been employed abroad, it seems to be reasonable to suppose that they represent two very different types of mobile star scientists. Expatriates have on average spent 30 years away from their home regions. This points to permanent migration and it can be assumed that these star scientists are, indeed, "lost" for their home regions. Returnees, in contrast, seem to be better categorized as temporary migrants, as they have lived and worked abroad on average six years before relocating back home. Thus, in the following movements of expatriates and returnees will be analyzed separately.

As mentioned above the sample covers 181 expatriates. The overwhelming majority of them (110 stars) have migrated to the United States. The key sending area of stars moving to the United States is Europe (61 star scientists), followed by Asia (15 stars), Canada (11 stars) and Oceania (10 stars). Europe provides jobs for 40 expatriates. Most of the expatriates employed in Europe come from European regions (a number of 26 stars), reflecting strong linkages between European labor markets via mobility of top researchers. There is comparatively little inflow of expatriate star scientists from outside Europe. Other world regions hardly play any

role in attracting expatriate top researchers. Given the dominating role of the United States in providing jobs for expatriates, in the following the analysis is mainly oriented on the US context, putting a special emphasis on movements of expatriates to the US islands of innovation. As shown above the US islands of innovation and research cities are major work places for expatriate star scientists, providing employment opportunities for not fewer than 86 foreign top researchers. At the same time, these regions hardly lose any native star scientists (see also Table 7). The European islands of innovation, in contrast, provide jobs for only 19 expatriate star scientists included in the sample. Where do the members of the foreign scientific elite employed in the top US regions with their innovative labor markets come from? As revealed in Figure 3 the US islands of innovation and research cities benefit from a rather strong inflow of European star scientists. A number of 15 stars migrated from European islands of innovation to the US top places, whilst movements of expatriates originating from other European countries are even more intense (23 stars).

Figure 3: Movements of expatriates to US and European islands of innovation and to US research cities

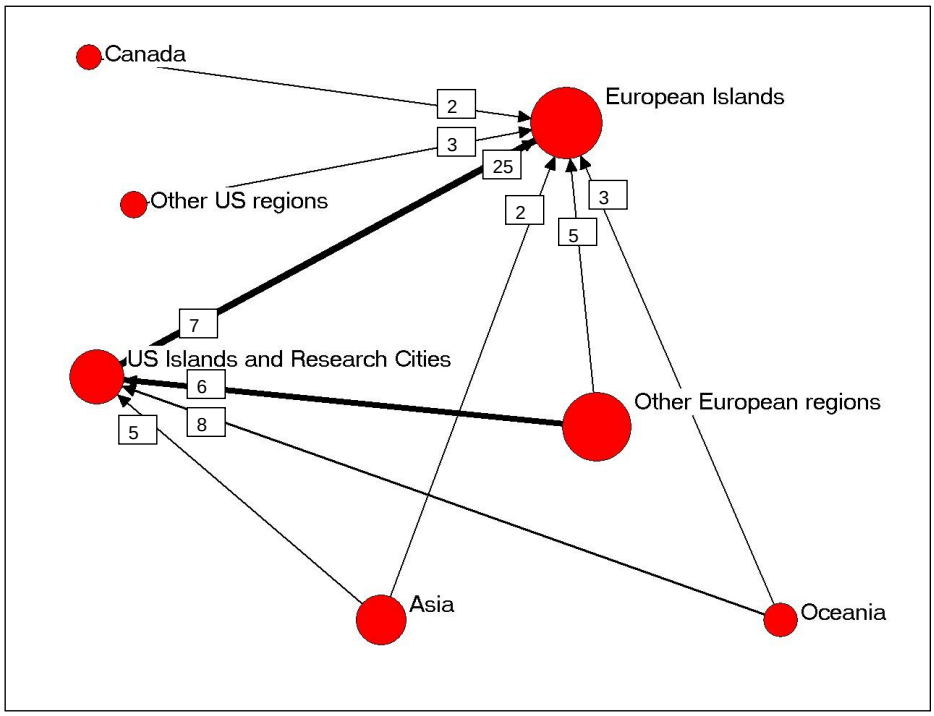


To summarize, there is evidence of networking relations between the US and European islands of innovation via mobile star scientists. At the same time a rather strong inflow of migrants from other European regions, Asia, Oceania, Canada and other parts of the world to the US islands of innovation and research cities could be observed. Consequently, it is particular non-islands of innovation which seem to lose many stars to the top US regions. This pattern might be explained by referring to the weak labor markets in these areas, which drive star scientists to move away and seek new employment opportunities in the innovative labor markets of superior US locations.

In a next step international movements of returnees are explored. As noted above, Europe in general and European islands of innovation in particular seem to be quite successful in luring top researchers back home. Out of a total number of 197 returnees included in the sample not fewer than 88 stars (45% of all returnees in the sample) could be found in Europe, whilst the United States provide employment opportunities for 48 returnees, representing a share of 25%

of all sampled returnees worldwide. There are strong linkages between the US and European labor markets via mobility of returnees. It is in particular Europe which benefits strongly from an inflow of returning stars who have been employed on a temporary basis in the US. Europe has attracted 54 returnees from the US, whilst flows in the opposite direction are less intense, amounting to 21 returnees.

Figure 4: Movements of returnees to US and European islands of innovation and to US research cities

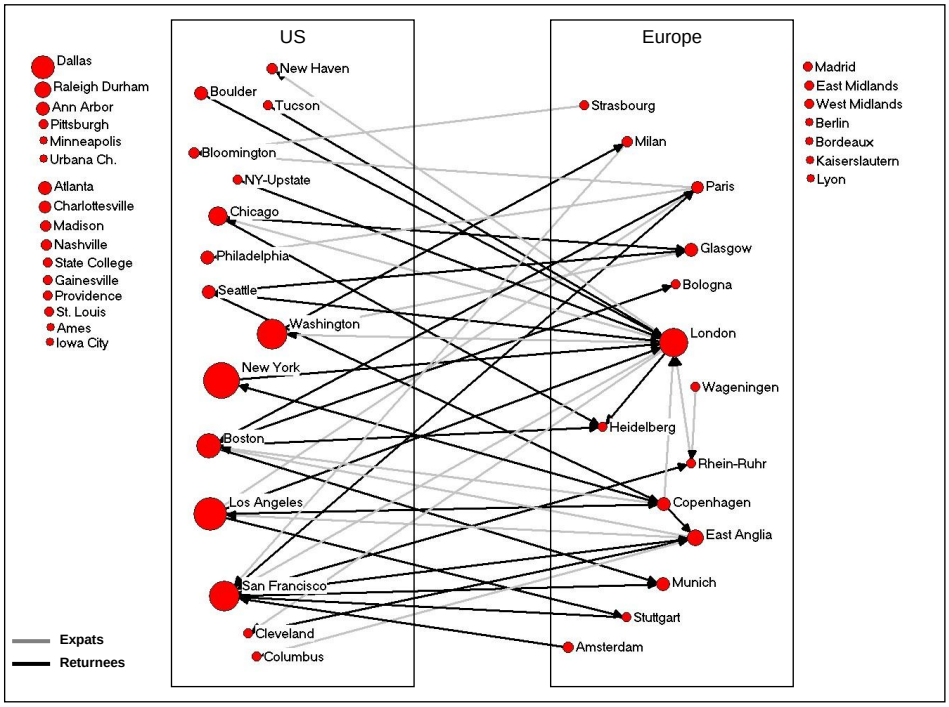


Also the exchange of returnees between European regions plays a role (18 returnees). Exploring the sending regions of returning European stars, points to an outstanding high importance of US islands of innovation and research cities. Very strong relations between these top places in the United States and European islands of innovation were found. Not less than 60% (a number of 25 stars) of the scientific elite who have relocated back home to a European island of innovation have temporarily worked in an US island of innovation or in a research city. Obviously, these top regions in the United States have an extraordinarily high attractiveness for distinguished researchers who decide to move away on a temporary basis. This might reflect their innovative labor markets for mobile star scientists. At the same time, it becomes clear, that the United States cannot retain all foreign-born top researchers who have flowed in. A different picture is found when looking at the main sending regions of US-stars who return to an US island of innovation or to a US research city (Figure 4). Returning US stars do not mainly come from European islands of innovation, but there is a larger set of sending regions.

Figure 5 shows the exchange of expatriates and returnees between the US islands of innovation and research cities and their counterparts in Europe. It is a few regions that play an outstanding role in this international network of innovative labor markets, acting as both crucial sending and receiving regions of mobile star scientists. These include San Francisco, Boston, London, East Anglia and Copenhagen. At the same time, it becomes clear, that a relatively large number of top US and European regions (such as Dallas/Houston/San Antonio, Raleigh Durham, Ann Arbor, Madrid, Berlin, etc.) do not take part in the networking of innovative labor markets. These areas rely exclusively on linkages with regions outside the

islands of innovation. Finally, Figure 5 also reveals another key characteristic of the international network of islands of innovation, that is, the very specific geography of linkages, which is strongly transcontinental in nature. Indeed, the overwhelming majority of ties are between US and European top places, whereas linkages between European islands of innovation are almost negligible.

Figure 5: International networking between innovative regional labor markets



6 Summary and Conclusions

Star scientists play a pivotal role in regional development, growth and innovation. They make major contributions to the advancement of science to technological breakthroughs, thus potentially providing key inputs for the rise of new science-based industries. Additionally, there is evidence that star scientists are also increasingly involved in the commercialization of scientific breakthroughs, thus, acting also as what ZUCKER and DARBY (2006) termed "star innovators". Given the crucial importance of these outstanding individuals for the evolution of regional knowledge economies and the development of science-based innovation, it is of utmost significance to identify those places and regions, where star scientists are educated, move to, come from and stay. Areas which provide innovative labor markets for top researchers and take part in the international exchange of the scientific elite have good chances to be amongst those places, where future science-based innovation will occur. Despite a growing interest in these issues, surprisingly little is still known about the location pattern and the geography of international movements of the very best and brightest scientific minds.

In this paper an attempt was made to examine the importance of islands of innovation and the role of their regional labor markets in this context. It has been shown that star scientists are strongly concentrated in a few places, highlighting the crucial role that is played by islands of innovation and their dynamic labor markets in providing employment opportunities for these outstanding researchers. Generally, this finding holds true for both the United States and

Europe. In the United States the pattern of geographical concentration of the surveyed members of the scientific elite is even more intense, reflecting the existence of a rather homogeneous institutional-set up and a common research area, whilst the comparatively more even distribution of stars in Europe is probably the outcome of rather strong differences between European nations in terms of language, culture and research, educational and science systems. Islands of Innovation do not only provide employment opportunities for many star scientists, but they have also contributed to a high extent to the "production" (i.e., education) of the surveyed members of the scientific elite. Obviously, the educational role of these areas reproduces and further strengthens their capacity to perform as islands of innovation. As major educational centers the islands of innovation perform a strong capacity to retain or re-attract stars educated there. For the US islands it was also found, that they succeed in attracting stars trained in other US islands of innovation. Furthermore, it was shown that islands of innovation perform as major centers in the process of international brain circulation, playing a key role in attracting internationally mobile star scientists. However, there are clear differences between the US and the European islands of innovation. The US islands were found to be highly successful in attracting expatriates. At the same time there is hardly any evidence that they lose native-born stars. Compared to the United States, the European islands of innovation perform less well when it comes to attract foreign star scientists. However, they are highly successful in luring returnees back home. Exploring the geography of movements of star scientists revealed a very specific pattern of exchange relations between regional labor markets. The analysis pointed to linkages between US and European islands of innovation via mobility of expatriates, uncovering very one way flows from Europe to the United States. At the same time evidence for a rather strong inflow of top scientists from other parts of the world to US islands of innovation and research cities was found. Tracking the mobility of returnees, strong exchange relations between US and European islands of innovation were found. The net flow is biased in one direction, clearly favoring the top regions in Europe. Overall, a densely knit web of linkages between the islands of innovation investigated here was detected. It was shown that their innovative labor markets form an international network via the exchange of expatriates and returnees. However, not all islands of innovation and research cities do take part in this network. Another key feature of the network is its highly transcontinental nature. The overwhelming majority of linkages is between the US and European top places, whilst only very few ties between European islands of innovation were found.

The arguments raised in this article allow for some concrete policy conclusions. Arguably, to create and further develop an attractive labor market for star scientists appears to be one key ingredient (amongst others) for future processes of science-based innovation. Those regions which have the capacity to develop such labor markets can participate in international world-class research by attracting and retaining top researchers, who further attract outstanding scientists and young research talent. Consequently, to actively recruit star scientists, to provide international mobility schemes for top researchers, to establish and keep at forefront internationally renowned universities and prestigious research facilities, to secure the availability of the best and latest scientific equipment, to provide excellent education opportunities for young talent and high-quality living conditions turn out to be crucial policy actions. The creation of innovative labor markets empowers regions to be amongst the leading centers of scientific research, to participate in the international exchange of outstanding researchers and to potentially become core centers of the commercialization of the knowledge embodied in these individuals.

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