# Location and Mobility of Star Scientists, Regional and National

Lynne G. Zucker
Michael R. Darby
UCLA and NBER

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## Location and Mobility of Star Scientists, Regional and National

In this paper, we abstract from, and occasionally quote, three papers by Zucker and Darby (2006; 2007a; 2007c) that draw upon the star scientist and engineer data base we have constructed from the ISIHighlyCited.com$^{SM}$ website (Institute for Scientific Information 2005b). The ISI Highly Cited scientists and engineers identifies the top 250 individual researchers in terms of 20-year-rolling-window citation counts in each of 21 subject fields – 19 of which are science and engineering fields. Information for each highly cited author includes a curriculum vitae (usually full but sometimes abbreviated), a list of publications taken from the author's curriculum vitae, and links for those publications in ISI-listed journals to the full bibliographic information indexed in the *ISI Web of Science®* (Institute for Scientific Information 1981-1997, 2005a). Based on these data, we identify 5,401 star scientists, collectively authoring some 520,839 articles that appear in the *ISI Web of Science®* database. The articles are used to identify where the stars are active based on those 299,583 cases (52.5 percent of the appearances of stars as authors) where their affiliation is unambiguous.[1]

Several questions immediately come to mind. Why the highly cited? There are both theoretical and practical considerations: (1) Stars are the ones making the major discoveries, and as a result hold tacit knowledge that is naturally excludable and embodied in the scientist; and (2) Stars are highly productive so that they can be tracked

[1] ISI article data do not distinguish which address (normally an organization) goes with which author, providing a list of all addresses, with the one exception of the corresponding author. Besides the corresponding author case, a definite person-address link can be established for sole authored articles or articles on which there is only one listed corresponding or research address (for journals that report multiple addresses on other articles that year).

through publications (and often patents) sufficiently to allow geographic location and mobility to be reliably tracked.

We were also guided in our choice of the highly cited scientists and engineers by our earlier empirical results in biotechnology, confirmed for firm founding and size of IPO in nanotechnology. In biotechnology, active stars have a the strong impact of on firm founding, and when tied to a firm - by co-authoring research article(s) - on firm products, patents, timing and size of IPO, and size and volatility of financial returns (many of these results are summarized in Darby and Zucker 2003). While impact on commercial and financial success of firms is one we have particularly explored, scientific stars have also been associated with very high productivity on the unusually small scientific teams they form (Zuckerman, 1967; 1977).

Now we turn to some empirical results flowing from the star measures, drawn from Zucker and Darby (2006, 2007c and d). We consider where the stars begin their professional careers, change regions or locations of residence and/or enter new scientific fields. Economic geography identifies agglomeration and diffusion, which are two sides of the same coin: Agglomeration increases over time with concentration so that regions or countries with larger values of this measure have disproportionately high growth rates for the same measure while those with lower values have disproportionately low growth rates. High-technology industries, for example, tend to concentrate over time or agglomerate in a relatively few centers, and knowledge in a specialty or subspecialty tends to grow faster in centers which have achieved a ‘critical mass’ of scholars (Zucker, Darby, Furner, Liu and Ma 2007). Diffusion is the mirror image of agglomeration:

regions or countries with smaller values have disproportionately high growth rates for the measure being considered while those with higher values have disproportionately low growth rates. Diffusion is the goal of many economic development schemes, notably in the European Union, as well as a natural process for the spread of knowledge.

The correlation coefficient of the level and growth rate of a variable measured across regions or countries and over time is a direct index of agglomeration or diffusion. If the correlation coefficient (which ranges from -1 to 1) is positive, the variable is agglomerating while a negative correlation coefficient shows that the variable is diffusing over time. In Table 2, taken from Zucker and Darby (2007d), and adapted there from Table 5 in Zucker and Darby (2007c) and Table 8 in Zucker and Darby (2006), whether we look at US regions or any of the listed combinations of the top-25 S&T countries in the world, university article publication is diffusing, with traditionally weaker regions and countries tending to catch up with traditional scientific leaders. This suggests that more regions and countries will over time provide a fertile ground for new star scientists to emerge where before it would be very difficult. This observation is confirmed – but more weakly – by the tendency for high impact articles (those that are very highly cited by other scientists) to diffuse, although that diffusion is statistically significant only where the US is not included in the set of countries. (In the interests of simplicity, I am skipping line 3 of the table on firm entry which is not covered here).

Star scientists entry shows strong agglomeration and tends to drive agglomeration of the number of star scientists resident in a region or country unless offset by migration (Zucker and Darby 2007c). Overlaying this pattern during the last quarter century, however, are movements of many US trained foreign students who build successful careers in American academe, perhaps moving from lower to higher ranked US universities but choose to return home when their native countries develop sufficient strength in their disciplines to both seek them out and to be attractive (Saxenian 2005). This weakens the tendency toward concentration when the US is in the country data set, but not when it is out. Since this effect is present to a somewhat similar degree in all American universities, the reverse brain drain of expatriate stars affects the average growth rate of stars in the US without weakening the positive correlation across countries.

Table 3 is taken from Zucker and Darby 2007d (based on Table 6 in Zucker and Darby 2007c), presents novel evidence on the location and migration of star scientists and engineers among the top-25 S&T countries. About 93 percent of the world's star scientists and engineers in the world have residences in the top-25 S&T countries at the end of 2004 – 62 percent in the US alone. It should be noted that non-US scientists suspect that ISI citation measures and therefore the ISI Highly Cited are inherently biased in favor of English-speaking and particularly American scientists (and, in fact, there must be published English translations of titles and abstracts for a non-English language to be ISI-listed). The dominant factor determining the number of stars resident in a country at the end of the period or at any time during the period is the number of professional debuts made in the country. Future stars are more likely to get their first job where they want to live and they tend to stay there. However, migration does make a difference for some countries and losing even one or two dominant firms founded by emigrants to other countries can be a significant economic event.

Table 3 shows clear evidence of reversal of the traditional brain drain from other countries, particularly less developed ones, to the US and other science powerhouses like Britain and Germany. The four largest net immigrations of star scientists over the last quarter century were registered by the United Kingdom (-27 or 4.6 percent of all stars resident in the country at any time 1981-2004), the United States (-23 or 0.6 percent), Canada (-23 or 7.7 percent) and Germany (-11 or 3.0 percent). Recall that Table 1 showed that for biotechnology stars (defined by genetic-sequence discoveries, not citations) 1973-1989, the US and Germany had inward net migration of 2.9 and 8.3 percent, respectively; so for these countries there is evidence of a reversal of direction.

For the six developing countries near the bottom of Table 3, round-trip inward migration (where a star moves there for more than two years but later leaves) provides a significant source of brain power and innovation accounting for from 33 to 79 percent of all star scientists ever resident in those countries, 1981-2004. Moreover, about 20 percent of all inward migrant stars to these countries had not returned as of 2004, mostly due to those remaining in China and Taiwan.

At this point we read the evidence on migration of stars as cautionary for the US, but alarming for some other countries (such as Canada, Germany, Israel and the United Kingdom). We also see hope for some developing countries that inward migration (frequently of native born, foreign-educated stars) can provide an important supplement to home-grown stars if working and living conditions are right to attract and retain them (Zucker and Darby 2007c).

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Table 2

Agglomeration or Diffusion? Correlation Coefficients for the Levels and Growth Rates of Articles, Firm Entry and Star Scientists & Engineers

| | Professional Debuts[b] | Outward Migration | | Inward Migration | | Net Inward Migration[e] | Net Stock[f] | Unique Persons[g] |
|---|---|---|---|---|---|---|---|---|
| | | One-way[c] | Round-trip[d] | One-way[c] | Round-trip[d] | | | |
| **OECD Member Countries** | | | | | | | | |
| Europe | | | | | | | | |
| Austria | 14 | 6 | 1 | 2 | 20 | -4 | 10 | 36 |
| Belgium | 37 | 7 | 1 | 2 | 15 | -5 | 32 | 54 |
| Denmark | 29 | 5 | 3 | 5 | 15 | 0 | 29 | 49 |
| Finland | 14 | 2 | 1 | 0 | 7 | -2 | 12 | 20 |
| France | 135 | 20 | 19 | 22 | 114 | 2 | 137 | 265 |
| Germany | 222 | 35 | 17 | 24 | 123 | -11 | 211 | 362 |
| Italy | 60 | 14 | 11 | 16 | 47 | 2 | 62 | 120 |
| Netherlands | 78 | 10 | 4 | 8 | 30 | -2 | 76 | 115 |
| Norway | 12 | 2 | 1 | 3 | 13 | 1 | 13 | 27 |
| Poland | 6 | 4 | 3 | 1 | 15 | -3 | 3 | 22 |
| Spain | 13 | 1 | 1 | 8 | 29 | 7 | 20 | 49 |
| Sweden | 70 | 12 | 7 | 5 | 40 | -7 | 63 | 112 |
| Switzerland | 80 | 17 | 7 | 27 | 45 | 10 | 90 | 148 |
| United Kingdom | 424 | 70 | 31 | 43 | 122 | -27 | 397 | 581 |
| *Europe[a]* | *1194* | *205* | *107* | *166* | *635* | *-39* | *1155* | *1960* |
| APEC Member Countries | | | | | | | | |
| Non-U.S. APEC Countries | | | | | | | | |
| Australia | 97 | 15 | 10 | 25 | 49 | 10 | 107 | 170 |
| Canada | 201 | 51 | 13 | 28 | 72 | -23 | 178 | 300 |
| Japan | 176 | 5 | 15 | 18 | 76 | 13 | 189 | 266 |
| South Korea | 1 | 0 | 0 | 4 | 7 | 4 | 5 | 12 |
| *Non-U.S. APEC[a]* | *475* | *71* | *38* | *75* | *204* | *4* | *479* | *748* |
| United States | 3354 | 142 | 276 | 119 | 216 | -23 | 3331 | 3670 |
| *APEC Countries[a]* | *3829* | *213* | *314* | *194* | *420* | *-19* | *3810* | *4418* |
| ***OECD Member Countries[a]*** | ***5023*** | ***418*** | ***421*** | ***360*** | ***1055*** | ***-58*** | ***4965*** | ***6378*** |
| **OECD Nonmember Countries** | | | | | | | | |
| Brazil | 1 | 1 | 0 | 3 | 15 | 2 | 3 | 19 |
| China | 4 | 1 | 0 | 11 | 26 | 10 | 14 | 39 |
| India | 10 | 3 | 1 | 3 | 14 | 0 | 10 | 27 |
| Israel | 57 | 13 | 5 | 4 | 28 | -9 | 48 | 86 |
| Russia/USSR | 7 | 4 | 0 | 4 | 27 | 0 | 7 | 36 |
| Taiwan | 3 | 1 | 0 | 5 | 6 | 4 | 7 | 14 |
| ***OECD Nonmember Countries[a]*** | ***82*** | ***23*** | ***6*** | ***30*** | ***116*** | ***7*** | ***89*** | ***221*** |
| **Top-25 S&T Countries[a]** | **5105** | **441** | **427** | **390** | **1171** | **-51** | **5054** | **6599** |
| **Top-24 Non-U.S. S&T Countries[a]** | **1751** | **299** | **151** | **271** | **955** | **-28** | **1723** | **2929** |

Source: Adapted from Zucker and Darby (2007c), Table 5, and Zucker and Darby (2006), Table 8.

Notes:
a. Totals of individual country values have not been adjusted for doublecounting due to within-region migration.
b. Each person who publishes or patents giving an address in the country the first year that person publishes or patents anywhere is counted as making a professional debut in the country. It is possible for one star to make a professional debut in more than one country and in a country other than the country of his or her birth or citizenship.
c. One-way immigration refers to the person stopping publishing or patenting in a country where they had been doing so and starting doing that in another country with no subsequent return to the first country. "Visits" of 2 years or less do not count for inward or outward migration.
d. Round-trip immigration refers to the person stopping publishing or patenting in a country where they had been doing so and starting doing that in another country and subsequently returning to the first country. "Visits" of 2 years or less do not count for inward or outward migration.
e. Net inward migration is one-way inward migration minus one-way outward migration. Round-trip inward and outward migration leave the stock of stars unchanged.
f. The net stock of stars is the number making professional debuts in the country plus one-way inward migration minus one-way outward migration, with no adjustment for death or retirement due to lack of information on when that occurs.
g. Unique persons is a count of the number of stars who have ever published or patented with an address in the country.

# Table 3
## Star Scientists' Professional Debuts and Migration Rates
## Top-25 Science and Technology Countries, 1981-2004

| | Professional Debuts[b] | Outward Migration | | Inward Migration | | Net Inward Migration[e] | Net Stock[f] | Unique Persons[g] |
|---|---|---|---|---|---|---|---|---|
| | | One-way[c] | Round-trip[d] | One-way[c] | Round-trip[d] | | | |
| **OECD Member Countries** | | | | | | | | |
| Europe | | | | | | | | |
| Austria | 14 | 6 | 1 | 2 | 20 | -4 | 10 | 36 |
| Belgium | 37 | 7 | 1 | 2 | 15 | -5 | 32 | 54 |
| Denmark | 29 | 5 | 3 | 5 | 15 | 0 | 29 | 49 |
| Finland | 14 | 2 | 1 | 0 | 7 | -2 | 12 | 20 |
| France | 135 | 20 | 19 | 22 | 114 | 2 | 137 | 265 |
| Germany | 222 | 35 | 17 | 24 | 123 | -11 | 211 | 362 |
| Italy | 60 | 14 | 11 | 16 | 47 | 2 | 62 | 120 |
| Netherlands | 78 | 10 | 4 | 8 | 30 | -2 | 76 | 115 |
| Norway | 12 | 2 | 1 | 3 | 13 | 1 | 13 | 27 |
| Poland | 6 | 4 | 3 | 1 | 15 | -3 | 3 | 22 |
| Spain | 13 | 1 | 1 | 8 | 29 | 7 | 20 | 49 |
| Sweden | 70 | 12 | 7 | 5 | 40 | -7 | 63 | 112 |
| Switzerland | 80 | 17 | 7 | 27 | 45 | 10 | 90 | 148 |
| United Kingdom | 424 | 70 | 31 | 43 | 122 | -27 | 397 | 581 |
| *Europe[a]* | *1194* | *205* | *107* | *166* | *635* | *-39* | *1155* | *1960* |
| APEC Member Countries | | | | | | | | |
| Non-U.S. APEC Countries | | | | | | | | |
| Australia | 97 | 15 | 10 | 25 | 49 | 10 | 107 | 170 |
| Canada | 201 | 51 | 13 | 28 | 72 | -23 | 178 | 300 |
| Japan | 176 | 5 | 15 | 18 | 76 | 13 | 189 | 266 |
| South Korea | 1 | 0 | 0 | 4 | 7 | 4 | 5 | 12 |
| *Non-U.S. APEC[a]* | *475* | *71* | *38* | *75* | *204* | *4* | *479* | *748* |
| United States | 3354 | 142 | 276 | 119 | 216 | -23 | 3331 | 3670 |
| *APEC Countries[a]* | *3829* | *213* | *314* | *194* | *420* | *-19* | *3810* | *4418* |
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| **OECD Nonmember Countries** | | | | | | | | |
| Brazil | 1 | 1 | 0 | 3 | 15 | 2 | 3 | 19 |
| China | 4 | 1 | 0 | 11 | 26 | 10 | 14 | 39 |
| India | 10 | 3 | 1 | 3 | 14 | 0 | 10 | 27 |
| Israel | 57 | 13 | 5 | 4 | 28 | -9 | 48 | 86 |
| Russia/USSR | 7 | 4 | 0 | 4 | 27 | 0 | 7 | 36 |
| Taiwan | 3 | 1 | 0 | 5 | 6 | 4 | 7 | 14 |
| ***OECD Nonmember Countries[a]*** | ***82*** | ***23*** | ***6*** | ***30*** | ***116*** | ***7*** | ***89*** | ***221*** |
| **Top-25 S&T Countries[a]** | **5105** | **441** | **427** | **390** | **1171** | **-51** | **5054** | **6599** |
| **Top-24 Non-U.S. S&T Countries[a]** | **1751** | **299** | **151** | **271** | **955** | **-28** | **1723** | **2929** |

Source: Zucker and Darby (2007c)

Notes:
a. Totals of individual country values have not been adjusted for doublecounting due to within-region migration.
b. Each person who publishes or patents giving an address in the country the first year that person publishes or patents anywhere is counted as making a professional debut in the country. It is possible for one star to make a professional debut in more than one country and in a country other than the country of his or her birth or citizenship.
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d. Round-trip immigration refers to the person stopping publishing or patenting in a country where they had been doing so and starting doing that in another country and subsequently returning to the first country. "Visits" of 2 years or less do not count for inward or outward migration.
e. Net inward migration is one-way inward migration minus one-way outward migration. Round-trip inward and outward migration leave the stock of stars unchanged.
f. The net stock of stars is the number making professional debuts in the country plus one-way inward migration minus one-way outward migration, with no adjustment for death or retirement due to lack of information on when that occurs.
g. Unique persons is a count of the number of stars who have ever published or patented with an address in the country.