MOVEMENT OF STAR SCIENTISTS
AND ENGINEERS
AND HIGH-TECH FIRM ENTRY

Lynne G. Zucker
Michael R. Darby

Working Paper 12172
http://www.nber.org/papers/w12172

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
April 2006

This research has been supported by grants from the National Science Foundation (grants SES-0304727 and SES-0531146) and the University of California's Industry-University Cooperative Research Program (grants PP9902, P00-04, P01-02, and P03-01). We are indebted to our research team members Emre Uyar, Jason Fong, Robert Liu, Tim Loon, Hongyan Ma, and Amarita Natt. Certain data included herein are derived from the Science Citation Index Expanded, Social Sciences Citation Index, Arts & Humanities Citation Index, and High Impact Papers of the Institute for Scientific Information®, Inc. (ISI®), Philadelphia, Pennsylvania, USA: © Copyright Institute for Scientific Information®, Inc. 2005. All rights reserved. Certain data included herein are derived from the Zucker-Darby Knowledge, Innovation, and Growth Project: © Lynne G. Zucker and Michael R. Darby. All rights reserved. The views expressed herein are those of the author(s) and do not necessarily reflect the views of the National Bureau of Economic Research.

Movement of Star Scientists and Engineers and High-Tech Firm Entry
Lynne G. Zucker and Michael R. Darby
NBER Working Paper No. 12172
April 2006
JEL No. O31, J61, O33, J44, M13

ABSTRACT

This paper extends the concept of star scientist to all areas of science and technology. We follow 1,838 stars' careers 1981-2004, using their publication history to locate them each year. 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. Thus the stars themselves rather than their potentially disembodied discoveries play a key role in the formation or transformation of high-tech industries. Other measures of academic knowledge stocks have weaker and less consistent effects. We identify separate economic geography effects in poisson regressions for the 179 BEA-defined U.S. regions, but not for the 25 countries analysis. Stars become more concentrated over time, moving from areas with relatively few peers to those with many in their discipline. A special counter-flow operating on the U.S. versus the other 24 countries is the tendency of foreign-born American stars to return to their homeland when it develops sufficient strength in their area of science and technology. In contrast high impact articles and university articles and patents all tend to diffuse, becoming more equally distributed over time.

Lynne G. Zucker
Professor of Sociology & Public Policy
Director, Center for International Science,
Technology, and Cultural Policy, SPA
Department of Sociology
University of California, Los Angeles
Los Angeles, CA 90095-1551
and NBER
zucker@ucla.edu

Michael R. Darby
W.E. Cordner Distinguished Professor of
Money & Financial Markets in the
Departments of Management, Economics,
& Public Policy
Anderson Graduate School of Management
University of California, Los Angeles
Los Angeles, CA 90095-1481
and NBER
darby@ucla.edu

Movement of Star Scientists and Engineers and High-Tech Firm Entry

Lynne G. Zucker and Michael R. Darby

In a series of articles, we have provided evidence that for rapidly advancing science and technology areas such as biotechnology, individual “star” scientists making major discoveries play an important role in determining where and when new or previously existing firms begin using the new technologies and which firms are most successful (Zucker and Darby 1996, 2001, 2006; Zucker Darby and Brewer 1998; Zucker, Darby, and Armstrong 1998, 2002; Darby and Zucker 2001, 2006a). This paper expands on that work in three major ways: First, we focus on the question of whether or not the star scientist has an independent role separate from the discoveries he or she makes. Second, we expand our coverage of science base to all areas covered by the Science Citation Index and our coverage of firms expands to all those for which U.S. patents have been assigned on issue or with which authors of articles are affiliated in the Science Citation Index, 1981-2004. Third, we provide evidence on 25 countries which do most of the world’s scientific research and commercial innovation instead of concentrating on one or two countries.[1]

We show here that star scientists do have a statistically and substantially significant impact on firm entry even after accounting for such measures of local knowledge stock as high-impact (highly cited) articles except those with firm authors, all publications by university authors except those with firm co-authors, and U.S. patents assigned at issue to universities. Since the embodied knowledge, insight, taste, and energy of the stars plays a role separate from their potentially disembodied discoveries, this evidence strengthens the case for the importance of the work of these extraordinary individuals for the economic development of regions and nations. Furthermore, while the distribution of knowledge stock measures shows a slight tendency – if anything – toward more evenness over time, the distribution of star scientists becomes significantly more concentrated in the leading centers over time. Counts of non-university patents show a less consistent dependence on the local presence of star scientists.

Section I lays out the analytical approach and hypotheses to be examined. We discuss the data set and estimation methodology in Section II. Our empirical results are reported in the next section. We summarize the results and draw our conclusions in Section IV.

I. Analytical Approach and Hypotheses

As in our prior work we assume that the probability λ that a firm will begin to use a given type of new technology through birth or change in focus in a particular country or region is small for an arbitrarily short period of time, so that entry occurs randomly over time in accordance with the poisson process. While the poisson process is frequently used to characterize the distribution of failures – such as light bulbs burning out – it is useful for characterizing countable events of a positive nature as well. The probability λ is assumed to vary across regions and years according to $\log \lambda = x\beta$ where x is a row vector of the explanatory variables and β is a parameter vector to be estimated.[2] In our previous work the significant explanatory variables have been primarily measures of the knowledge base in the region and of the economic geography (employment and average wage per job as a proxy for education level of the local labor force).

Zucker and Darby (1996) and Zucker, Darby, and Brewer (1998) introduced the concept of biotechnology stars based upon productivity measured by the number of articles written through 1990 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, Darby, and Armstrong 1998, 2002; Zucker and Darby 2001). In this paper we reformulate the concept of star scientist and engineers to encompass nearly 2000 very productive authors across the range of science and engineering topics covered in the Science Citation Index. By including the number active in a region and year as an explanatory variable, we specifically investigate whether these extraordinary individuals play an independent role in promoting the entry of firms into their area of science and technology when their discoveries are accounted for in measures of the local knowledge stocks of high impact articles, all university articles, and university patenting. Based on our biotechnology work, we hypothesize that they do have a separate positive impact on λ, but acknowledge controversy as to how far beyond biotechnology and other high-science-driven areas that effect will be present.

We hypothesize that a very similar process explains commercial development in the form of non-university patenting, although the corresponding λ would surely be of larger magnitude per unit of time. Since stars mostly patent in the university (even stars affiliated with firms most often have a primary appointment with a university), we hypothesize that their effect on non-university patenting is likely to be weaker but still present. Moreover, we believe that it is interesting to quantify the effects of the academic knowledge stocks more generally on regional patenting.

II. Empirical Methodology

Our empirical analysis focuses on entry of firms and non-university patenting over time and by U.S. regions or by countries. The data bases for this study have been substantially enlarged in both size and coverage from those used in any other study of which we are aware.

Section II.A describes the data used in the empirical analysis. Section II.B summarizes the standard estimation methodology.

II.A. The Data

The primary source databases for the analysis are the complete, continuously updated and parsed U.S. Patent database of the Zucker-Darby Knowledge, Innovation, and Growth Project and the *Science Citation Index Expanded, Social Sciences Citation Index, Arts & Humanities Citation Index, and High Impact Papers* of the Institute for Scientific Information®, Inc. (ISI®, 2005). Our patent data cover the 3,891,720 U.S. patents granted by USPTO from 1976 to 2005. The ISI database contains more than 24,250,000 records from over 8700 peer-reviewed scientific journals. Other sources are noted where relevant.

Although our data cover all countries, computational considerations led us to limit our analysis to the 25 top science and engineering countries defined as all countries that had one or more authors on at least 0.5% of all ISI articles or that had one or more inventors on at least 0.1% of all U.S. patents granted, 1976-2004, or both. These “top-25 science and technology (S&T) countries” are: Australia, Austria, Belgium, Brazil, Canada, China, Denmark, Finland, France, Israel, India, Italy, Japan, Germany, the Netherlands, Norway, Poland, South Korea, Spain, Sweden, Switzerland, Taiwan, the United Kingdom, the United States, and (counted as the same country) the USSR and Russia. These 25 countries account for 92.8% of all ISI articles and 99.3% of U.S. patents.

These data are used to create two analysis data sets containing data from 1981 through 2004 for each of the 179 U.S. regions and also for each of 25 top science and engineering countries (including the U.S.). These longitudinal (panel) data sets consist of 179 regions x 24 years = 4,296 observations and 25 countries x 24 years = 600 observations, respectively. Some analysis is done with the U.S. deleted from the country data set, leaving 576 observations.

The variables in each data set are categorized into six science and technology areas: Biology, Chemistry & Medicine; Computing & Information Technology; Semiconductors, Integrated Circuits & Superconductors; Nanoscale Science & Technology; Other Sciences; and Other Engineering. Each observation with valid organizational information in the research and reprint address fields (articles) or assignee-at-issue field (patents) is categorized as a firm or university and otherwise put in a miscellaneous other category which includes governmental organizations and research institutes. For purposes of locating observations, each valid U.S. address in these fields is assigned to a county and the corresponding region using the Federal Information Processing Standard (FIPS55) database maintained by the U.S. Geological Survey. (http://geonames.usgs.gov/fips55.html). Foreign addresses are grouped based on the country of origin. The variables contained in the data sets and their summary statistics are listed in Table 1. Their construction is described immediately below.

II.A.1. Science and Technology Areas

Tushman and Anderson (1986) emphasize the stability in the science and technology base of a given firm so that it is a major and perilous event to enter a new area of technology comparable to birth of a start-up firm with its own science and technology base. Mansfield (1995) focuses on the ties between particular industries and academic disciplines. Darby and Zucker (1999) attempt to capture these insights in a set of seven area clusters which can be used to compare activity in journal articles (Institute for Scientific Information 1981-1997), university doctoral programs (National Research Council 1995), and patents (Zucker and Darby 1999a). These clusters are used here with two exceptions: First, the humanities and social sciences are dropped for this study because they have little specific applicability to particular high technology industries. Second, we have been developing a public digital library NanoBank.org for the emergent, highly interdisciplinary nanotechnologies which utilize the unique properties that occur at the atomic and sub-atomic level (Zucker and Darby 2006b). We subtract those articles and patents identified for NanoBank.org from the area in which they would have been previously classified. Those nanotechnology patents are identified as the union of a standard Boolean search of titles, abstracts, and patent descriptions using nano-specific terms and an iterative probabilistic method which scores words and phrases according to their relative frequency of appearance in a learning set of expert-identified nano-articles and articles and patents generally (Ma, Furner, Zucker, and Darby 2006; Zucker, Darby, Ma, Furner, and Liu 2006). The Data Appendix Table A.1 details the Web of Science subject category codes, International Patent Classes, and National Research Council doctoral program names corresponding to each of these six science and technology areas.

II.A.2. Star Scientists and Engineers

Zucker and Darby 1996 and Zucker, Darby, and Brewer (1998) introduced the concept of biotechnology stars based upon productivity measured by the number of articles written through 1990 which reported a genetic-sequence discovery. We test here a generalization of that productivity standard based on authorship of frequently cited articles, especially those included in the *High Impact Papers* database of the ISI which reports the top 200 articles each year in terms of citations across 21 major fields. We have so far collected data on 1,838 (compared to our earlier-defined 327 biotechnology stars) including curricula vitae and all the papers (284,527 articles) we can match into the ISI's *Science Citation Index Expanded, Social Sciences Citation Index,* and *Arts & Humanities Citation Index* databases. A reprint or research address could be attached unambiguously to the individual star for about 54% of these articles.[3] We have used these addresses to identify each U.S. region or non-U.S. country in which these star scientists were active 1981-2004. We code the stars as active in a region from two years before their first publication there (based on research and publication lags in a 40-star CV study) until they move to another location. During transitional phases they are coded as active for up to two years in both locations. Stars who maintain long-term affiliations in multiple countries also are coded as active in each location. Finally, an author is assumed to remain in their last location in the years following their last observed article.

The author is assigned to each of one or more science and technology areas in those years when that area is reflected in the article keywords (author keywords and ISI Keywords Plus) appearing in all of their publications (whether we have an assured location or not). This potential double-counting of both areas and locations is rare in practice the average number of stars per year across all countries, areas, and years is only 2,200 or 19.7% more than the 1,838 unique individuals. Nonetheless, we believe that it more accurately captures the ability of these extraordinary individuals to catalyze the founding of a firm or entry of an existing firm into a new technology area.

II.A.3. Firm Entry into a New Area of Technology

Darby and Zucker (2006) have shown that the first time in which a firm publishes an article in an area is a good indicator of entry into high-technology industries. We generalize that approach here by counting as entry the first-to-appear publication with a firm-affiliated author or patent assigned to the firm at the time the patent is granted (assignee at issue). For the country data set, a particular firm can enter each time it first publishes or patents in a given technology area in a given country. For the U.S. date set, a particular firm can enter each time it first publishes or patents in a given technology area in a given region. Thus, entries by a firm in a given area and U.S. region are not counted in the country data set after the first time the firm enters that technology area in any region in the U.S. In practice, the vast majority of firms publish and/or patent in only a single area and single country or region as defined by the addresses of authors or inventors.

It is important to emphasize that having used articles with firm-affiliated authors and patents with firm assignees to define our primary dependent variable, such articles and patents cannot be used in the construction of any of the independent variables for the empirical analysis.

II.A.4. Non-University Patenting

The second dependent variable non-university patenting measures an aspect of the development of commercial technology by region or country. We use non-university patenting (i.e., patents with no university as assignee at issue) rather than firm patents because the bulk of those patents not assigned to identified firms or universities appear to be commercial in nature although we have not identified the assignee as a particular firm. These patents are geolocated by the inventors' addresses as a more reliable indicator of where the research was done than the assignee address which is often the firm's headquarters. Where there are $n > 1$ inventors, the patent is counted as $1/n$ for the location of each inventor's address.

II.A.5. Knowledge Stocks

We used three separate sources to develop measures of the non-firm science base by region (or country) and year: university articles, university patents, and high impact articles. In constructing these measures we first delete all articles for which a firm is included on any of the reprint and research addresses (articles) or as an assignee at issue since those articles or patents could have been used to define entry and introduce a subtle bias into the analysis. High impact articles are those in the *High Impact Papers* database of the ISI cited above. University articles and patents are those with a university (but no firm) named either any of the reprint and research addresses or as an assignee at issue. High-impact articles exclude only those with firm authors, but are nearly all also included in the university articles file.

Knowledge stocks are measured as conventional (see Griliches 1990) in the economics of science and technology literature as a perpetual inventory with depreciation rate $\delta = 0.20$:

$$(1) \qquad K_{i,t} = I_{i,t} + (1 - \delta)K_{i,t-1}$$

where $K_{i,t}$ is the knowledge stock of type i (denoting science and technology area and region or country) at time t and $I_{i,t}$ is the input series for this knowledge stock – alternatively counts by region/country and science and technology area of (non-firm) university articles, university patents, and high impact articles.

While creating the input series counts for each of these measures, we determine the articles or patents in each science and technology area. (If an article or patent that can be considered belonging to more than one area, each area is credited a fraction.[4]) These science and technology area counts are then allocated to U.S. regions and/or to countries with each research address or assignee address receiving equal credit.[5] For example, if an article had seven authors and listed two British addresses and one French address, Britain would get two thirds of the article's credit and France one-third since we cannot assign each of the seven authors to any particular research address. After creating the basic counts for each year by area and region or country, we use formula (1) to accumulate them year by year with a 20% depreciation rate to create the knowledge stocks by science and technology area, region or country, and year for each of the two analysis data sets (U.S. regions and top-25 science and technology countries).

II.A.6. Other Variables

The employment and average wage-per-job data for the U.S. regional data set were downloaded from the BEA website (http://www.bea.gov/bea/regional/reis/) and the wages were deflated to thousands of 2000 dollars per year using the BEA's chain-type price index for consumer expenditures. The employment data for the 25-country data set were obtained from IMF (http://ifs.apdi.net/imf/) with the exception of Taiwan data which were downloaded from http://2k3dmz2.moea.gov.tw/gnweb/english/e_main.aspx?Page=D. Missing observations were interpolated by linear regressions.

II.B. Estimation Method

There is some controversy among practitioners as to the best method to estimate count models with a poisson-like structure. The mean and variance of the poisson distribution both equal the single parameter λ. However, overdispersion (variance > mean) will be observed if there is unobserved heterogeneity across observations. This is frequently dealt with by assuming that the parameter λ is distributed according to

(2) $\log \lambda = x\beta + \varepsilon$

where the disturbance term ε is distributed as a gamma distribution. Kennedy (1998, pp. 247-248) notes that this "leads to a negative binomial distribution for the number of occurrences, with mean λ and variance $\lambda + \alpha^{-1}\lambda^2$ where α is the common parameter of the gamma distribution." Estimation by negative binomial – or worse, we believe, negative binomial if poisson fails a pretest for overdispersion – is a frequent recourse for dealing with potential overdispersion.

We have continually avoided this practice in our own work because if the binomial is inappropriate (i.e., ε is not gamma-distributed) the estimated coefficients will be biased with the negative binomial method while these coefficients are estimated without bias using the poisson method even if the negative binomial method is appropriate. We are persuaded by Wooldridge (1991) that the better way to deal with possible overdispersion (and underdispersion which also occurs) is to estimate standard errors for the coefficients which are unbiased across a range of plausible models. In the past we have used Wooldridge's regression based method which works but requires writing your own subroutine. We are now using the Stata 9.0 statistical package which includes robust standard errors as an option for poisson estimation which solves the problems discussed by Wooldridge and others.

III. Empirical Results

This section discusses our empirical results for both firm entry (III.A) and non-university patenting (III.B). We use the Stata 9.0 statistical package for poisson estimation with robust standard errors for all the estimates presented in these subsections for the reasons just discussed. The third subsection examines whether the major determinants in these regressions are becoming more diffuse or more concentrated over time.

III.A. Entry into New Technology Areas

Our empirical results for entry of firms into new (to them) science and technology areas are reported in Table 2 for the U.S. regions data set, Table 3 for the top-25 science and technology countries data set, and Table 4 for the top-24 non-U.S. science and technology countries data set.

First, however, it is important to emphasize the major result: 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. These effects are numerically substantial as illustrated in Figure 1.

The first 6 quartets of bars in Figure 1 illustrate the effects of stars in U.S. regions (Table 2), the next 6 represent these effects for the 25 country regressions (Table 3), and the last six for the 24 countries with the U.S. excluded (Table 4). The second bar in each quartet represents the base for comparison (value 1.00) which is the probability per unit of time of firm entry if all variables in the poisson regressions are set equal to their mean value. The first bar represents the probability of firm entry if there were instead exactly one active star in the science and technology area in an otherwise representative region or country divided by the probability if all variables were at their mean. Therefore, the first bar is lower than the second in cases where the mean number of active stars is greater than one and higher if that mean is less than one. The third and fourth bars in a quartet represent the relative probability of firm entry when the active stars are set 1 or 2 standard deviations above their mean.

For example, the first quartet plotted is for the Biology, Chemistry & Medicine based on the U.S. regional regressions. It shows that a region with 2 standard deviations more stars than average in this area will have nearly double the probability of a firm entering the area on any given day as compared to an otherwise like region with only the mean number of active stars. For all 25 countries, the corresponding ratio is 12.7 times the base probability. Thinking that this might reflect something special about the U.S., we excluded it in the 24-country regressions but still have a 6.6-fold probability for a country with 2 standard deviations above average active stars compared to a country with the mean number of stars.

Figures 2-5 compare cumulative active star years (stars) and firm entry (circles) in U.S. and world for biology/chemistry/medicine and nanotechnology. The size of the stars and circles indicate the numbers of each, but note the change in scale in moving from Figure 2 to 3 or 4 to 5.

Focusing now on Table 2, we see that the stars do not merely have an additional effect on firm entry over and above that of the discoveries by them and others included in the high impact articles, university articles, and university patents knowledge stocks, but that these variables are not even consistently positive in their impact with stars included.[6] This seems to say that top scientists and engineers are the ferment driving the formation and transformation of high-tech firms, not their inventions separate from themselves. The economic geography variables seem to be well behaved, with both the size of the region and the average education level (captured here by average wage) having significant positive effects on the entry of firms into new areas. The dummy variables were included to capture the fact that some of the entries which will be eventually observed using our methodology cannot be seen yet since many applied for patents from 2002-2004 were still pending when our data set was created and even some articles to appear in journals with 2004 cover dates had yet to be published. These dummies had the expected negative sign and increasing size indicating increasing truncation effects.

The results for the 25-country regressions in Table 3 are similar to Table 2 with the notable exception that the university articles stock does appear to have a consistent significant and positive effect on firm entry. Economic geography lost its consistent effects, perhaps because of our inability to find a commensurable average wage or education level variable and perhaps also because of the very large size of China and India. The 2002-2004 dummy variables follow the same general pattern to the extent they are significant, but for 2 areas they are mostly insignificant.

We were concerned that something special about American institutions or culture or simply a greater propensity to obtain a U.S. patent might distort the results in Table 3, so we reran all the poisson regressions with the U.S. excluded from the data set. The results are remarkably similar to those in Table 2, suggesting that the U.S. was not an unduly influential observation.

Taken as a whole, the results show that the physical presence of star scientists and engineers plays an important role in the formation and transformation of high-tech firms. There is some evidence, especially in the country regressions, that academic discoveries (or unmeasured discoverers) play an independent role as well. The economic geography variables work well in the U.S. regional context, but do not translate well in the international context.

III.B. Non-university Patenting

Our attempt to explain non-university patenting using stars, academic knowledge stocks, and economic geography were not so successful as reported in Tables 5, 6, and 7. The university articles knowledge stock does show consistent positive effects in the country regressions (Tables 6 and 7), but this is not true for the U.S. regional results. Our problem may be that the three knowledge stocks are correlated not only among themselves but with the star counts. Apparently, any positive effect of the local academic knowledge stock or stars is much weaker than is the case for firm entry into new science and technology areas.

While the results for patenting are not commensurate with the effort that went into the analysis, they do illustrate one important point: There is nothing inherent in the empirical methodology that artificially

III.C. Concentration or Diffusion of Stars and Knowledge

Given the clear importance of stars for firm entry and – in the country regressions – also the university articles knowledge stock, it is interesting to know how these change over time. Table 8 reports the correlation coefficients between the growth rates and levels of stars and each of the three knowledge stock variables by science and technology area. If this correlation is significantly positive, it means that those regions with above average levels of the variable are also growing faster in percentage terms implying increasing concentration over time: the rich get richer. On the other hand, a significant negative value of this correlation coefficient means below average regions or countries are growing more rapidly and above average ones less rapidly implying diffusion or a tendency toward equalization over time.

Stars show a clear tendency toward concentration by area in both the U.S. regional data set and for the 24 non-U.S. countries, with the effect weakest for the Biology, Chemistry, and Medicine area. This pattern is much weaker in the 25 country data set where all correlations are positive but only 1 (nanotechnology) more than marginally significant. We interpret these results as reflecting two contradictory motivations for movement of stars. First stars tend to move to where there are more other stars – for example from lower to higher ranked universities – as well as to where there are greater commercial opportunities (Zucker and Darby (1999b).[7] Overlaying this pattern during the last quarter century, however, are movements of many U.S. trained foreign students who build successful careers in American academe, perhaps moving from lower to higher ranked U.S. 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. This weakens the tendency toward concentration when the U.S. 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 U.S. without weakening the positive correlation across countries.

For the knowledge stocks in the U.S regions and 25 countries data sets, there is a general tendency toward diffusion or equalization of knowledge stocks, with significant negative correlations appearing most consistently for university articles – possibly the diffusion of the "publish or perish" standard from elite American universities to others both domestically and internationally. Domestic diffusion may have kept up the overall growth rate of American knowledge stocks, since the pattern of diffusion of university articles and even high impact articles is much stronger among the 24 non-U.S. countries.

IV. Conclusions and Agenda for Future Work

We have shown that it is possible to generalize the definition of star scientists and engineers far beyond its biotechnology origins. We have also seen that doing so offers convincing evidence that these extraordinary people play a key role in the formation and transformation of high-tech firms. We have seen that while there is a general tendency toward diffusion of academic knowledge stocks, the movement of star scientists and engineers is toward concentration. One offsetting trend is the tendency for foreign-born American academics to return home when their country becomes strong in their disciplines.

Data Appendix

[Table A.1 goes here]

References

Darby, Michael R., and Lynne G. Zucker, *California's Science Base: Size, Quality and Productivity*, Sacramento, CA: California Council on Science and Technology, 1999.

Darby, Michael R., and Lynne G. Zucker, "Change or Die: The Adoption of Biotechnology in the Japanese and U.S. Pharmaceutical Industries," *Comparative Studies of Technological Evolution*, 2001, 7: 85-125.

Darby, Michael R., and Lynne G. Zucker, "Grilichesian Breakthroughs: Inventions of Methods of Inventing in Nanotechnology and Biotechnology," *Annales d'Economie et Statistique*, 2006 in press.

Griliches, Zvi, "Patent Statistics as Economic Indicators: A Survey," *Journal of Economic Literature*, December 1990, 28(4):1661-1707.

Institute for Scientific Information, *Science Citation Index*, machine-readable data bases, Philadelphia: Institute for Scientific Information, 1981-1997.

Institute for Scientific Information, *Science Citation Index Expanded, Social Sciences Citation Index, Arts & Humanities Citation Index, and High Impact Papers,* machine-readable data bases, Philadelphia: Institute for Scientific Information, 2005.

Johnson, Kenneth P. and John R. Kort "2004 Redefinition of the BEA Economic Areas," *Survey of Current Business*, November 2004, pp. 68-75.

Kennedy, Peter, *A Guide to Econometrics*, fourth edition, Cambridge, MA: The MIT Press, 1998.

Ma, Hongyan, Jonathan Furner, Lynne G. Zucker, and Michael R. Darby, "Automatic Selection of Patents and Scientific Articles for NanoBank: An Integrated Probabilistic (IP)

Approach," paper for presentation at the ACM & IEEE Computing Joint Conference on Digital Libraries, 2006.

National Research Council., *Research-Doctorate Programs in the United States: Data Set*, machine-readable data base, Washington, DC: National Academy Press, 1995.

Tushman, Michael L., and Philip Anderson, "Technological Discontinuities and Organizational Environments," *Administrative Science Quarterly*, March 1986, 31(1): 439-465.

Wooldridge, Jeffrey M., "On the Application of Robust, Regression-Based Diagnostics to Models of Conditional Means and Conditional Variances," *Journal of Econometrics*, January 1991, 47: 5-46.

Zucker, Lynne G., and Michael R. Darby, "Star Scientists and Institutional Transformation: Patterns of Invention and Innovation in the Formation of the Biotechnology Industry," *Proceedings of the National Academy of Sciences*, November 12, 1996, 93(23): 12709-12716.

Zucker, Lynne G., and Michael R. Darby, *California's Inventive Activity: Patent Indicators of Quantity, Quality, and Organizational Origins*, California Council on Science and Technology, 1999. (1999a)

Zucker, Lynne G., and Michael R. Darby, "Star Scientist Linkages to Firms in APEC and European Countries: Indicators of Regional Institutional Differences Affecting Competitive Advantage," *International Journal of Biotechnology*, 1999, 1(1): 119-131. (1999b)

Zucker, Lynne G., and Michael R. Darby, "Capturing Technological Opportunity Via Japan's Star Scientists: Evidence from Japanese Firms' Biotech Patents and Products," *Journal of Technology Transfer*, January 2001, 26(1/2): 37-58.

Zucker, Lynne G., and Michael R. Darby, "Real Effects of Policy Change in Industry Development in Stem Cells," paper presented at the Stem Cells: Promise and Peril in Regenerative Medicine Conference, UCLA Center for Society and Genetics, Los Angeles, CA, February 3-4, 2006. (2006a)

Zucker, Lynne G., and Michael R. Darby, "Socio-economic Impact of Nanoscale Science: Initial Results and NanoBank," in Mihail C. Roco and William S. Bainbridge, eds., *Societal Implications of Nanotechnology*, Springer Science and Business Media, 2006 in press. (2006b)

Zucker, Lynne G., Michael R. Darby, and Jeff Armstrong, "Geographically Localized Knowledge: Spillovers or Markets?" *Economic Inquiry*, January 1998, 36(1): 65-86.

Zucker, Lynne G., Michael R. Darby, and Jeff Armstrong, "Commercializing Knowledge: University Science, Knowledge Capture, and Firm Performance in Biotechnology," *Management Science*, January 2002, 48(1): 138-153.

Zucker, Lynne G., Michael R. Darby, and Marilynn B. Brewer, "Intellectual Human Capital and the Birth of U.S. Biotechnology Enterprises," *American Economic Review*, March 1998, 88(1): 290-306.

Zucker, Lynne, Michael R. Darby, Hongyan Ma, Jonathan Furner, and Robert Liu, "Knowledge and Organizational Prologues of the Evolution of Nanotechnology," National Bureau of Economics Research Working Paper No. [in process], March 2006.

Zucker, Lynne G., Michael R. Darby, and Máximo Torero, "Labor Mobility from Academe to Commerce," *Journal of Labor Economics*, July 2002, 20(3): 629-660.

Footnotes

[1] The 25 countries are: Australia, Austria, Belgium, Brazil, Canada, China, Denmark, Finland, France, Israel, India, Italy, Japan, Germany, the Netherlands, Norway, Poland, South Korea, Spain, Sweden, Switzerland, Taiwan, the United Kingdom, the United States, and the USSR & Russia counted as the same country.

[2] If $\lambda = X\beta + \varepsilon$ (i.e., has a disturbance term ε) and if so the distribution of ε affects the estimation methodology used as discussed in Section II.B below.

[3] Unless the star is the designated person to write for a reprint, a certain match can be made only if he or she is the sole author (in which case all reprint or research addresses are assigned as affiliations of the author) or where there is only one reprint and research address and the publishing journal's practice is listing all the addresses of authors (in which case the star is deemed affiliated with the sole address).

[4] Each International Patent Classification code and each ISI Web of Science category code has been associated with one major science and technology area. Since patents can report more than one IPC code (and journals more than one ISI category), we can have observations associated with more than one major science and technology area. If a patent (or article) has n IPC codes (or n ISI categories), each science and technology area is credited with 1/n for that patent (article) for each IPC code (ISI category) on it which falls in the area.

[5] If an article has research address listed they include the reprint address and so that is not counted again. If there is only a reprint address, full credit for the article goes to that location. Since this assignment is made by address, the sum of the U.S. regional assignments exactly equals the number assigned to it in the 25-country data set.

[6] In results not reported here, we checked that these variables do have their usual positive impact

if stars are excluded from the regressions.

[7] A seemingly related paper, Zucker, Darby, and Torero (2002), focused not on inter-regional or international mobility of biotech stars, but mobility from purely academic to either affiliated or linked (co-authoring) with firm scientists.

Table 1. Summary Statistics for Variables Used in Empirical Analysis, 1981-2004

Variables	U.S. Regions					Top-25 Sci. & Tech Countries					Top-24 non-U.S S&T Countries				
	N	Mean	S.D.	Min	Max	N	Mean	S.D.	Min	Max	N	Mean	S.D.	Min	Max
Entry of Firms into:															
Biology/Chemistry/Medicine	4296	4.9	12.0	0	125	600	45.7	148.8	0	1063	576	17.2	21.0	0	94
Computing/Information Technology	4296	2.1	7.6	0	173	600	20.6	80.1	0	729	576	5.8	8.4	0	49
Nanotechnology	4296	1.0	3.9	0	57	600	12.4	53.1	0	475	576	3.6	7.4	0	53
Semiconductors	4296	2.5	6.9	0	91	600	24.5	80.6	0	657	576	8.8	11.9	0	76
Other Sciences	4296	2.3	6.2	0	74	600	24.5	88.8	0	607	576	7.2	11.2	0	56
Other Engineering	4296	7.2	17.0	0	163	600	72.4	284.4	0	2074	576	19.8	34.7	0	180
Non-university patenting:															
Biology/Chemistry/Medicine	4296	37.5	220.1	0	3,215.3	600	725.9	2,204.5	0	15,687.2	576	314.1	648.5	0	4,017.7
Computing/Information Technology	4296	23.2	224.4	0	4,801.5	600	445.2	1,744.6	0	14,160.7	576	205.9	834.7	0	9,093.1
Nanotechnology	4296	10.4	85.5	0	2,462.8	600	246.2	973.1	0	8,079.8	576	137.1	623.8	0	7,863.8
Semiconductors	4296	5.7	59.2	0	1,398.4	600	162.3	550.7	0	4,544.8	576	94.5	348.0	0	3,029.1
Other Sciences	4296	13.1	69.0	0	1,145.8	600	310.5	905.6	0	6,681.7	576	157.2	444.0	0	4,087.5
Other Engineering	4296	81.8	394.3	0	5,799.2	600	2,275.0	6,431.5	0	43,214.8	576	1,187.7	3,126.4	0	23,374.2
Star Scientists & Engineers Active															
Biology/Chemistry/Medicine	4296	5.0	15.3	0	121	600	57.1	186.8	0	1140	576	19.6	26.0	0	130
Computing/Information Technology	4296	0.8	3.0	0	30	600	8.2	28.0	0	169	576	2.6	3.4	0	17
Nanotechnology	4296	0.2	0.9	0	12	600	2.0	7.2	0	58	576	0.8	1.7	0	10
Semiconductors	4296	1.1	3.8	0	43	600	11.2	40.7	0	270	576	3.1	3.3	0	19
Other Sciences	4296	0.6	2.4	0	26	600	6.3	21.5	0	132	576	2.0	3.3	0	17
Other Engineering	4296	0.3	1.2	0	11	600	3.3	11.6	0	76	576	1.0	1.8	0	11
High Impact Articles Knowledge Stock															
Biology/Chemistry/Medicine	4296	13.1	55.0	0	518.9	600	277.3	834.2	0	4,911.6	576	115.0	156.2	0	870.3
Computing/Information Technology	4296	2.5	11.5	0	123.5	600	58.4	162.4	0	1,194.3	576	27.0	34.6	0	248.2
Nanotechnology	4296	0.5	2.9	0	65.9	600	15.1	53.7	0	513.1	576	7.6	14.4	0	96.9
Semiconductors	4296	2.0	9.7	0	115.4	600	53.4	146.1	0	907.9	576	25.3	32.0	0	137.1
Other Sciences	4296	5.0	25.1	0	246.0	600	96.7	324.2	0	1,994.1	576	34.7	52.6	0	269.4
Other Engineering	4296	1.3	7.3	0	75.2	600	30.4	91.2	0	528.3	576	12.6	18.7	0	103.4
University Articles Knowledge Stock															
Biology/Chemistry/Medicine	4296	1,485.0	5,068.2	0	61,361.2	600	46,272.6	108,860.9	64.0	729,673.6	576	26,210.2	31,255.5	64.0	159,973.2
Computing/Information Technology	4296	90.9	317.1	0	3,803.9	600	3,501.5	7,268.2	6.0	49,950.6	576	2,207.5	2,476.7	6.0	12,449.2
Nanotechnology	4296	20.0	94.2	0	1,509.7	600	953.9	2,557.6	0	24,685.3	576	654.0	1,338.9	0	9,289.5
Semiconductors	4296	159.7	577.8	0	6,030.3	600	7,438.5	13,386.2	24.4	81,232.2	576	5,198.3	6,455.8	24.4	36,102.0
Other Sciences	4296	99.7	374.2	0	4,161.1	600	3,245.2	7,703.8	3	48,111.6	576	1,816.8	2,207.4	3	11,874.8
Other Engineering	4296	44.0	158.6	0	1,691.6	600	1,534.7	3,622.9	1	23,672.5	576	875.5	1,166.2	1	7,241.4
University Patents Knowledge Stock															
Biology/Chemistry/Medicine	4296	9.1	48.6	0	740.4	600	134.0	690.7	0	5,404.6	576	13.5	36.4	0	261.6
Computing/Information Technology	4296	0.7	4.2	0	70.4	600	11.3	62.2	0	590.4	576	1.1	3.4	0	33.4
Nanotechnology	4296	3.6	28.9	0	651.7	600	53.2	344.1	0	3,745.5	576	4.7	16.9	0	236.5
Semiconductors	4296	0.3	2.8	0	61.4	600	5.7	28.8	0	298.9	576	0.7	4.4	0	94.1
Other Sciences	4296	2.3	15.5	0	305.1	600	34.7	166.8	0	1,302.7	576	4.0	10.4	0	61.6
Other Engineering	4296	3.4	19.2	0	383.1	600	61.9	296.0	0	2,376.6	576	8.4	19.6	0	127.3
Total Employment in Region/Country	4296	0.8	1.4	0.0	12.9	600	47.3	123.3	1.0382	752	576	44.2	124.9	1.0	752.0
Average Wage per Job in Region	4296	26.2	4.1	18.3	51.0	—	—	—	—	—	—	—	—	—	—

Notes: 1. The science and engineering areas are Biology/Chemistry/Medicine; Computing & Information Technology; Semiconductors, Integrated Circuits & Superconductors; Nanoscale Science & Technology; Other Sciences; and Other Engineering. Nanoscale Science & Technology articles & patents as defined for NanoBank.org are removed from the other five areas into which they would otherwise be classified.

2. U.S. regions are the 179 functional economic areas defined by the U.S. Bureau of Economic Analysis (Johnson and Kort 2004).

Table 2. Firm Entry into New Technologies - Poisson Regressions
U.S. Functional Economic Regions, 1981-2004

	Science and Technology Areas of Firm Entry					
Explanatory Variables	Bio/Chem/Med	Computing/IT	Nanotechnology	Semiconductors	Other Sciences	Other Engineering
Star Scientists & Engineers Active in Region in Same S&T Area as Entry	0.0201*** (0.0016)	0.0573*** (0.0120)	0.1260*** (0.0303)	0.1266*** (0.0303)	0.0546*** (0.0100)	0.1387*** (0.0153)
High Impact Articles Knowledge Stock in Same S&T Area as Entry	-0.0007 (0.0006)	0.0282*** (0.0033)	0.0117 (0.0286)	0.0117 (0.0287)	0.0075*** (0.0010)	-0.0056 (0.0086)
University Articles Knowledge Stock in Same S&T Area as Entry	-0.0000 (0.0000)	-0.0017*** (0.0001)	-0.0017*** (0.0005)	-0.0016*** (0.0005)	-0.0008*** (0.0001)	-0.0010^ (0.0005)
University Patents Knowledge Stock in Same S&T Area as Entry	-0.0010^ (0.0006)	0.0162** (0.0061)	0.0002 (0.0027)	0.0002 (0.0027)	0.0045** (0.0016)	0.0046* (0.0019)
Total Employment in Region/Country (millions of persons)	0.1371*** (0.0185)	0.1868*** (0.0212)	0.1048*** (0.0240)	0.1048*** (0.0240)	0.2240*** (0.0238)	0.1986*** (0.0181)
Average Wage per Job in Region (thousands of 2000 dollars per year)	0.1108*** (0.0081)	0.1577*** (0.0100)	0.1954*** (0.0096)	0.1954*** (0.0096)	0.0998*** (0.0100)	0.1052*** (0.0082)
Constant	-1.9203*** (0.2133)	-4.1159*** (0.2635)	-5.7731*** (0.2622)	-5.7731*** (0.2622)	-2.3218*** (0.2645)	-1.2372*** (0.2203)
Dummy = 1 in 2002, else 0	-0.7639*** (0.1195)	-0.8968*** (0.1181)	-0.6132*** (0.1307)	-0.6132*** (0.1307)	-1.1105*** (0.1456)	-1.4557*** (0.1475)
Dummy = 1 in 2003, else 0	-0.9137*** (0.1136)	-1.4043*** (0.1594)	-0.9743*** (0.1433)	-0.9743*** (0.1433)	-1.2748*** (0.1431)	-1.8339*** (0.1573)
Dummy = 1 in 2004, else 0	-1.5195*** (0.1467)	-2.0044*** (0.1471)	-1.9980*** (0.1900)	-1.9980*** (0.1900)	-1.9722*** (0.1588)	-2.8430*** (0.1810)
Pseudo R^2	0.6130	0.6116	0.5399	0.5399	0.5257	0.5783

Notes: Robust standard errors in parentheses below coefficient estimates. N = 4296. Significance levels: ^ 0.10, * 0.05, ** 0.01, ***0.001

1. The science and engineering areas are Biology/Chemistry/Medicine; Computing & Information Technology; Semiconductors, Integrated Circuits & Superconductors; Nanoscale Science & Technology; Other Sciences; and Other Engineering. Nanoscale Science & Technology articles & patents as defined for NanoBank.org are removed from the other five areas into which they would otherwise be classified.
2. Knowledge stocks are computed as a perpetual inventory of the indicated series with 20% depreciation applied to the prior year's stock.

Table 3. Firm Entry into New Technologies - Poisson Regressions
Top-25 Science & Technology Countries, 1981-2004

	Science and Technology Areas of Firm Entry					
Explanatory Variables	Bio/Chem/Med	Computing/IT	Nanotechnology	Semiconductors	Other Sciences	Other Engineering
Star Scientists & Engineers Active in	0.0068***	0.0359***	0.0920***	0.0180*	0.0352***	0.0584***
Country in Same S&T Area as Entry	(0.0005)	(0.0040)	(0.0092)	(0.0078)	(0.0057)	(0.0131)
High Impact Articles Knowledge Stock	-0.0020***	-0.0071***	0.0001	-0.0032	-0.0029***	-0.0078^
in Same S&T Area as Entry	(0.0002)	(0.0016)	(0.0071)	(0.0028)	(0.0007)	(0.0041)
University Articles Knowledge Stock	0.0000***	0.0002***	0.0003***	0.0000*	0.0002***	0.0004***
in Same S&T Area as Entry	(0.0000)	(0.0000)	(0.0001)	(0.0000)	(0.0001)	(0.0001)
University Patents Knowledge Stock	-0.0008***	-0.0030*	-0.0018**	-0.0003	-0.0035***	-0.0014***
in Same S&T Area as Entry	(0.0001)	(0.0014)	(0.0007)	(0.0032)	(0.0006)	(0.0004)
Total Employment in Region/Country	-0.0015***	-0.0007**	0.0005	-0.0002	0.0007*	-0.0005
(millions of persons)	(0.0003)	(0.0003)	(0.0004)	(0.0004)	(0.0003)	(0.0003)
Constant	2.5778***	1.5135***	1.3448***	2.1579***	1.6944***	2.8567***
	(0.0564)	(0.0702)	(0.1289)	(0.1242)	(0.1071)	(0.0953)
Dummy = 1 in 2002, else 0	-0.1671	-0.4499*	-1.0568***	0.1835	-0.5838**	-0.8429***
	(0.1154)	(0.2028)	(0.2088)	(0.1769)	(0.2011)	(0.1777)
Dummy = 1 in 2003, else 0	-0.2387	0.5907**	-2.0026***	0.2395	-1.1386***	-1.2488***
	(0.1497)	(0.2090)	(0.3808)	(0.1868)	(0.2811)	(0.1361)
Dummy = 1 in 2004, else 0	-2.0226***	-0.9604***	-2.4310*	-0.3856	-2.4977***	-2.4802***
	(0.5257)	(0.2619)	(1.1740)	(0.2976)	(0.5284)	(0.4027)
Pseudo R^2	0.8805	0.8728	0.7609	0.7698	0.8691	0.8688

Notes: Robust standard errors in parentheses below coefficient estimates. N = 600. Significance levels: ^ 0.10, * 0.05, ** 0.01, ***0.001

1. The science and engineering areas are Biology/Chemistry/Medicine; Computing & Information Technology; Semiconductors, Integrated Circuits & Superconductors; Nanoscale Science & Technology; Other Sciences; and Other Engineering. Nanoscale Science & Technology articles & patents as defined for NanoBank.org are removed from the other five areas into which they would otherwise be classified.
2. Knowledge stocks are computed as a perpetual inventory of the indicated series with 20% depreciation applied to the prior year's stock.

Table 4. Firm Entry into New Technologies - Poisson Regressions
Top-24 Non-U.S. Science & Technology Countries, 1981-2004

Explanatory Variables	Bio/Chem/Med	Computing/IT	Nanotechnology	Semiconductors	Other Sciences	Other Engineering
Star Scientists & Engineers Active in Country in Same S&T Area as Entry	0.0362*** (0.0010)	0.1227*** (0.0108)	0.3449*** (0.0187)	0.0925*** (0.0057)	0.1506*** (0.0060)	0.2965*** (0.0120)
High Impact Articles Knowledge Stock in Same S&T Area as Entry	-0.0041*** (0.0003)	-0.0051 (0.0037)	-0.0053 (0.0053)	0.0025 (0.0022)	0.0056** (0.0008)	-0.0132*** (0.0040)
University Articles Knowledge Stock in Same S&T Area as Entry	0.0000*** (0.0000)	0.0003*** (0.0000)	0.0003*** (0.0001)	0.0001*** (0.0000)	0.0000 (0.0000)	0.0003*** (0.0001)
University Patents Knowledge Stock in Same S&T Area as Entry	0.0014*** (0.0002)	0.0249*** (0.0055)	0.0013** (0.0004)	0.0249*** (0.0044)	0.0009 (0.0008)	0.0074*** (0.0008)
Total Employment in Region/Country (millions of persons)	0.0003 (0.0002)	0.0003 (0.0002)	0.0006 (0.0004)	-0.0002 (0.0003)	0.0013*** (0.0003)	0.0007* (0.0003)
Constant	1.2085*** (0.0227)	0.3874*** (0.0345)	-0.0729^ (0.0402)	0.6189*** (0.0290)	0.5908*** (0.0293)	1.8315*** (0.0283)
Dummy = 1 in 2002, else 0	-0.2171* (0.0931)	-0.4000* (0.1895)	-0.3360 (0.2802)	-0.0986 (0.10390	-0.4913*** (0.1395)	-0.9846*** (0.1688)
Dummy = 1 in 2003, else 0	-0.2114* (0.0913)	-0.6378** (0.2396)	-0.7480*** (0.1957)	-0.1377 (0.1306)	-0.6530*** (0.1361)	-1.2866*** (0.1555)
Dummy = 1 in 2004, else 0	-0.8256*** (0.1244)	-1.4304*** (0.2928)	-1.4542*** (0.2464)	-0.6130*** (0.1499)	-1.1451*** (0.1481)	-2.1226*** (0.1843)
Pseudo R^2	0.5511	0.4441	0.3508	0.4488	0.4266	0.3901

Notes: Robust standard errors in parentheses below coefficient estimates. N = 576. Significance levels: ^ 0.10, * 0.05, ** 0.01, ***0.001

1. The science and engineering areas are Biology/Chemistry/Medicine; Computing & Information Technology; Semiconductors, Integrated Circuits & Superconductors; Nanoscale Science & Technology; Other Sciences; and Other Engineering. Nanoscale Science & Technology articles & patents as defined for NanoBank.org are removed from the other five areas into which they would otherwise be classified.
2. Knowledge stocks are computed as a perpetual inventory of the indicated series with 20% depreciation applied to the prior year's stock.

Table 5. Non-University Patenting by Science & Technology Areas - Poisson Regressions
U.S. Functional Economic Regions, 1981-2004

	Science and Technology Areas of Patents					
Explanatory Variables	Bio/Chem/Med	Computing/IT	Nanotechnology	Semiconductors	Other Sciences	Other Engineering
Star Scientists & Engineers Active in	0.0105*	-0.0733*	0.1681***	0.0047	-0.0277	0.1898***
Region in Same S&T Area as Patent	(0.0045)	(0.0322)	(0.0352)	(0.0129)	(0.0252)	(0.0362)
High Impact Articles Knowledge Stock	0.0008	0.0492***	0.0291	0.0319***	0.0119***	-0.0601***
in Same S&T Area as Patent	(0.0017)	(0.0053)	(0.0285)	(0.0054)	(0.0009)	(0.0086)
University Articles Knowledge Stock	0.0000	-0.0002	0.0015**	0.0000	-0.0004*	0.0049***
in Same S&T Area as Patent	(0.0000)	(0.0003)	(0.0006)	(0.0002)	(0.0002)	(0.0004)
University Patents Knowledge Stock	-0.0021	-0.0035	-0.0043	0.0392***	0.0083***	-0.0067***
in Same S&T Area as Patent	(0.0014)	(0.0093)	(0.0030)	(0.0086)	(0.0025)	(0.0015)
Total Employment in Region	0.0701	0.1020	-0.0058	0.1157	0.2519**	0.0422
(millions of persons)	(0.1068)	(0.0672)	(0.0545)	(0.0760)	(0.0928)	(0.0291)
Average Wage per Job in Region	0.0968***	0.1681***	0.1881***	0.1009***	0.0559*	0.0875***
(thousands of 2000 dollars per year)	(0.0264)	(0.0311)	(0.0182)	(0.0215)	(0.0225)	(0.0169)
Constant	0.0865	-3.1430***	-3.8238***	-2.8274***	0.0661	1.1757**
	(0.6484)	(0.8360)	(0.4829)	(0.5652)	(0.5462)	(0.4310)
Dummy = 1 in 2002, else 0	-0.3399	0.0021	-0.1832	0.0006	-0.2834	-0.2133
	(0.3045)	(0.1319)	(0.2325)	(0.1606)	(0.2592)	(0.1761)
Dummy = 1 in 2003, else 0	-0.3971	-0.9515***	-0.5415^	-0.1146	-0.0864	-0.2633
	(0.3213)	(0.2425)	(0.2791)	(0.1840)	(0.1871)	(0.1679)
Dummy = 1 in 2004, else 0	-0.5210^	-0.2109	-0.5117*	0.1442	0.1292	-1.0076***
	(0.3085)	(0.2457)	(0.2588)	(0.1985)	(0.1871)	(0.2800)
Pseudo R^2	0.6830	0.8816	0.7613	0.8728	0.6688	0.6781

Notes: Robust standard errors in parentheses below coefficient estimates. N = 4296. Significance levels: ^ 0.10, * 0.05, ** 0.01, ***0.001

1. The science and engineering areas are Biology/Chemistry/Medicine; Computing & Information Technology; Semiconductors, Integrated Circuits & Superconductors; Nanoscale Science & Technology; Other Sciences; and Other Engineering. Nanoscale Science & Technology articles & patents as defined for NanoBank.org are removed from the other five areas into which they would otherwise be classified.
2. Knowledge stocks are computed as a perpetual inventory of the indicated series with 20% depreciation applied to the prior year's stock.

Table 6. Non-University Patenting by Science & Technology Areas - Poisson Regressions
Top-25 Science & Technology Countries, 1981-2004

	Science and Technology Areas of Patents					
Explanatory Variables	Bio/Chem/Med	Computing/IT	Nanotechnology	Semiconductors	Other Sciences	Other Engineering
Star Scientists & Engineers Active in Country in Same S&T Area as Patent	0.0062***	0.0054	0.0422***	0.0042	0.0112	0.0470***
	(0.0010)	(0.0172)	(0.0111)	(0.0043)	(0.0097)	(0.0143)
High Impact Articles Knowledge Stock in Same S&T Area as Patent	-0.0031***	-0.0091^	0.0016	-0.0079***	-0.0036***	-0.0152***
	(0.0003)	(0.0052)	(0.0024)	(0.0018)	(0.0010)	(0.0042)
University Articles Knowledge Stock in Same S&T Area as Patent	0.0000***	0.0003***	0.0006***	0.0002***	0.0003***	0.0006***
	(0.0000)	(0.0001)	(0.0000)	(0.0000)	(0.0001)	(0.0001)
University Patents Knowledge Stock in Same S&T Area as Patent	-0.0012***	-0.0073***	-0.0033***	-0.0078***	-0.0036***	-0.0017***
	(0.0001)	(0.0020)	(0.0002)	(0.0013)	(0.0006)	(0.0004)
Total Employment in Country (millions of persons)	-0.0011**	-0.0011^	-0.0024**	-0.0035***	-0.0002	-0.0005
	(0.0003)	(0.0006)	(0.0008)	(0.0007)	(0.0004)	(0.0004)
Constant	5.0271***	4.4331***	4.0203***	3.4673***	4.5243***	6.5946***
	(0.0679)	(0.1562)	(0.1226)	(0.1318)	(0.1110)	(0.0854)
Dummy = 1 in 2002, else 0	0.1136	0.0842	-0.5330**	0.4068*	0.2905	0.2679
	(0.1707)	(0.3092)	(0.1806)	(0.2079)	(0.3023)	(0.2832)
Dummy = 1 in 2003, else 0	-0.0361	1.3705***	-1.3551***	0.6233**	0.1413	0.2465
	(0.1457)	(0.4170)	(0.3892)	(0.2420)	(0.3945)	(0.3082)
Dummy = 1 in 2004, else 0	-2.6025***	0.5267	-1.0454**	0.2806	-0.6622	-0.7396
	(0.4423)	(0.4041)	(0.3709)	(0.3019)	(0.8177)	(0.5303)
Pseudo R^2	0.8658	0.6911	0.7837	0.7201	0.6446	0.6726

Notes: Robust standard errors in parentheses below coefficient estimates. N = 600. Significance levels: ^ 0.10, * 0.05, ** 0.01, ***0.001

1. The science and engineering areas are Biology/Chemistry/Medicine; Computing & Information Technology; Semiconductors, Integrated Circuits & Superconductors; Nanoscale Science & Technology; Other Sciences; and Other Engineering. Nanoscale Science & Technology articles & patents as defined for NanoBank.org are removed from the other five areas into which they would otherwise be classified.
2. Knowledge stocks are computed as a perpetual inventory of the indicated series with 20% depreciation applied to the prior year's stock.

Table 7. Non-University Patenting by Science & Technology Areas - Poisson Regressions
Top-24 Non-U.S. Science & Technology Countries, 1981-2004

	Science and Technology Areas of Patents					
Explanatory Variables	Bio/Chem/Med	Computing/IT	Nanotechnology	Semiconductors	Other Sciences	Other Engineering
Star Scientists & Engineers Active in Country in Same S&T Area as Patent	0.0185***	-0.1906***	-0.2142***	0.0355	-0.4217***	-0.4945***
	(0.0051)	(0.0409)	(0.0490)	(0.0335)	(0.0499)	(0.0647)
High Impact Articles Knowledge Stock in Same S&T Area as Patent	-0.0033**	-0.0335***	0.0250**	-0.0138	0.0164***	-0.0045
	(0.0011)	(0.0060)	(0.0088)	(0.0095)	(0.0045)	(0.0063)
University Articles Knowledge Stock in Same S&T Area as Patent	0.0000***	0.0007***	0.0005***	0.0002***	0.0004***	0.0011***
	(0.0000)	(0.0001)	(0.0001)	(0.0000)	(0.0001)	(0.0001)
University Patents Knowledge Stock in Same S&T Area as Patent	-0.0068***	0.0541***	0.0111***	0.0398***	-0.0282*	-0.0000
	(0.0013)	(0.0127)	(0.0011)	(0.0063)	(0.0127)	(0.0038)
Total Employment in Country (millions of persons)	-0.0012***	-0.0033***	-0.0038***	-0.0042***	-0.0011**	-0.0021***
	(0.0003)	(0.0007)	(0.0008)	(0.0011)	(0.0004)	(0.0004)
Constant	4.5318***	4.2076***	3.8601***	3.0754***	4.0135***	6.3667***
	(0.0757)	(0.1493)	(0.1211)	(0.2099)	(0.1258)	(0.0966)
Dummy = 1 in 2002, else 0	-0.0403	-0.6077**	-0.5479*	0.0409	0.0241	-0.5271*
	(0.1406)	(0.2260)	(0.2572)	(0.3169)	(0.1880)	(0.2075)
Dummy = 1 in 2003, else 0	-0.1031	0.5819^	-1.0259***	-0.0052	0.0737	-0.6959**
	(0.1504)	(0.3414)	(0.2963)	(0.3313)	(0.2361)	(0.2339)
Dummy = 1 in 2004, else 0	-0.6248***	-0.3216	-0.7396***	-0.8134*	0.4540	-0.7074**
	(.1266)	(0.3165)	(0.2227)	(0.4159)	(0.2956)	(0.2753)
Pseudo R^2	0.7160	0.6256	0.7385	0.6564	0.5467	0.5144

Notes: Robust standard errors in parentheses below coefficient estimates. N = 576. Significance levels: ^ 0.10, * 0.05, ** 0.01, ***0.001

1. The science and engineering areas are Biology/Chemistry/Medicine; Computing & Information Technology; Semiconductors, Integrated Circuits & Superconductors; Nanoscale Science & Technology; Other Sciences; and Other Engineering. Nanoscale Science & Technology articles & patents as defined for NanoBank.org are removed from the other five areas into which they would otherwise be classified.
2. Knowledge stocks are computed as a perpetual inventory of the indicated series with 20% depreciation applied to the prior year's stock.

Table 8. Correlation Coefficients for the Levels and Growth Rates of Star Scientists & Engineers and Knowledge Stocks

	Correlation Coefficients of Level and Growth Rate across Years and Regions/Countries by S&T Field						
	All Sci. & Eng.	Bio/Chem/Med	Computing/IT	Nanotechnology	Semiconductors	Other Sciences	Other Engineering
US Regions							
Star Scientists & Eng.	0.08***	0.09***	0.18***	0.36***	0.17***	0.27***	0.33***
High Impact Articles	-0.02	-0.02	-0.04	-0.02	-0.03	-0.02	-0.03
University Articles	-0.01	-0.01	-0.06*	-0.09**	-0.01	-0.05*	-0.04^
University Patents	-0.03	-0.03	-0.00	-0.02	-0.01	-0.01	-0.01
Top-25 S&T Countries							
Star Scientists & Eng.	0.00	0.02	0.05	0.19**	0.05	0.09^	0.07
High Impact Articles	-0.09*	-0.07^	-0.06	-0.08	-0.05	-0.05	-0.04
University Articles	-0.09*	-0.08^	-0.08*	-0.19***	-0.11**	-0.02	-0.04
University Patents	-0.02	-0.02	-0.04	-0.04	-0.03	-0.04	-0.02
Top-24 Non-US S&T Countries							
Star Scientists & Eng.	0.03	0.07^	0.24***	0.45***	0.35***	0.31***	0.33***
High Impact Articles	-0.17***	-0.14***	-0.02	-0.13*	-0.09*	-0.10*	-0.08^
University Articles	-0.17***	-0.15***	-0.14***	-0.24***	-0.16***	-0.03	-0.07^
University Patents	-0.03	-0.04	-0.10	0.09	-0.00	0.02	-0.02

Notes: Significance levels: ^ 0.10, * 0.05, ** 0.01, ***0.001

1. The science and engineering areas are Biology/Chemistry/Medicine; Computing & Information Technology; Semiconductors, Integrated Circuits & Superconductors; Nanoscale Science & Technology; Other Sciences; and Other Engineering. Nanoscale Science & Technology articles and patents as defined for NanoBank.org are removed from the other five areas into which they would otherwise be classified.

Data Appendix

Table A.1. Science-Area Concordance: Doctoral Programs, Web of Science Subject Categories & International Patent Codes

Darby-Zucker (1999) Area Name	Corresponding NRC (1995) Doctoral Programs	Corresponding Web of Science Subject Category Codes	Corresponding International Patent Classes
Biology, Chemistry, & Medicine	Biochemistry & Molecular Biology Cell & Developmental Biology Molecular & General Genetics Ecology, Evolution & Behavioral Biomedical Engineering Pharmacology Chemistry Neurosciences Physiology Chemical Engineering	AD,AE,AF,AH,AK,AM,AQ,AY,AZ,BA,BD,CN,CO, CQ,CU,CX,DA,DB,DE,DM,DQ,DR,DS,DW,DX,DY, EA,EC,EE,EI,EY,FF,FI,FQ,FY,GA,GM,GU,HB, HE,HL,HQ,HT,HY,IA,IG,IH,II,IY,JA,JY,KA,KI,KM, LI,LJ,LQ,MA,MU,NE,NI,NN,OI,OO,OP,PT,PW, PY,QA,QB,QU,RQ,RT,RU,RX,RZ,SA,SD,SU,TA, TC,TD,TI,TM,TQ,TU,UH,UM,UY,VE,VY,WC,WE, WF,WH,WV,XE,XW,YA,YO,YP,YU,ZA,ZC,ZD, ZE,ZM,ZR	A 61 B,A 61 C,A 61 D,A 61 F,A 61 G,A 61 H,A 61 J,A 61 K,A 61 L,A 61 M, A 61 N,A 61 P,B 01 J,B 01 L,C 01 B,C 01 C,C 01 D,C 01 F,C 01 G,C 02 F, C 03 B,C 03 C,C 04 B,C 05 B,C 05 C,C 05 D,C 05 F,C 05 G,C 06 B,C 06 C, C 06 D,C 06 F,C 07 B,C 07 C,C 07 D,C 07 F,C 07 G,C 07 H,C 07 J,C 07 K, C 07 M,C 08 B,C 08 C,C 08 F,C 08 G,C 08 H,C 08 J,C 08 K,C 08 L,C 09 B, C 09 C,C 09 D,C 09 F,C 09 G,C 09 H,C 09 J,C 09 K,C 10 B,C 10 C,C 10 F, C 10 G,C 10 H,C 10 J,C 10 K,C 10 L,C 10 M,C 10 N,C 11 B,C 11 C,C 11 D, C 12 C,C 12 F,C 12 G,C 12 H,C 12 J,C 12 L,C 12 M,C 12 N,C 12 P,C 12 Q, C 12 R,C 12 S,C 13 C,C 13 D,C 13 F,C 13 G,C 13 H,C 13 J,C 13 K,C 14 B, C 14 C
Computing & Information Technology	Computer Sciences Mathematics	AC,EP,ER,ES,ET,EV,EW, EX,PE,PN,PQ,RB,XY,YE	G 06 C,G 06 D,G 06 E,G 06 F,G 06 G,G 06 J,G 06 K,G 06 N,G 06 T, G 09 C,G 11 B,G 11 C
Semiconductors Integrated Circuits, High-temperature Superconductors	Physics Electrical Engineering Materials Science Mechanical Engineering	AA,DT,IQ,IU,PJ,PK,PM, PU,PZ,QF,QG,QH,QJ, QM,SR,SY,UB,UE,UF, UI,UK,UN,UP,UR,XQ,ZI	H 01 L
Other Sciences	Oceanography Astrophysics/Astronomy Statistics/Biostatistics Geosciences	GC,ID,JU,KV,KY,LE, OU,PI,QE,QQ,RA,RE, RO,SI,TE	C 30 B,G 01 B,G 01 C,G 01 D,G 01 F,G 01 G,G 01 H,G 01 J,G 01 K, G 01 L,G 01 M,G 01 N,G 01 P,G 01 R,G 01 S,G 01 T,G 01 V,G 01 W, G 02 B,G 02 C,G 02 F,G 21 B,G 21 C,G 21 D,G 21 F,G 21 G,G 21 H, G 21 J,G 21 K,H 01 S
Other Engineering	Aerospace Engineering Civil Engineering Industrial Engineering	AI,BU,FA,IF,IJ,IK,IL,IM, IO,IP,IX,OA,RY,YR,ZQ	All others — see note for current list.

Note: International Patent Classes corresponding to Other Engineering: A 01 B,A 01 C,A 01 D,A 01 F,A 01 G,A 01 H,A 01 J,A 01 K,A 01 L,A 01 M,A 01 N,A 21 B,A 21 C,A 21 D,A 22 B, A 22 C,A 23 B,A 23 C,A 23 D,A 23 F,A 23 G,A 23 J,A 23 K,A 23 L,A 23 N,A 23 P,A 24 B,A 24 C,A 24 D,A 24 F,A 41 B,A 41 C,A 41 D,A 41 F,A 41 G,A 41 H,A 42 B,A 42 C, A 43 B,A 43 C,A 43 D,A 44 B,A 44 C,A 45 B,A 45 C,A 45 D,A 45 F,A 46 B,A 46 D,A 47 B,A 47 C,A 47 D,A 47 F,A 47 G,A 47 H,A 47 J,A 47 K,A 47 L,A 62 B,A 62 C,A 62 D, A 63 B,A 63 C,A 63 D,A 63 F,A 63 G,A 63 H,A 63 J,A 63 K,B 01 B,B 01 D,B 01 F,B 02 B,B 02 C,B 03 B,B 03 C,B 03 D,B 04 B,B 04 C,B 05 B,B 05 C,B 05 D,B 06 B,B 07 B, B 07 C,B 08 B,B 09 B,B 09 C,B 21 B,B 21 C,B 21 D,B 21 F,B 21 G,B 21 H,B 21 J,B 21 K,B 21 L,B 22 C,B 22 D,B 22 F,B 23 B,B 23 C,B 23 D,B 23 F,B 23 G,B 23 H,B 23 K, B 23 P,B 23 Q,B 24 B,B 24 C,B 24 D,B 25 B,B 25 C,B 25 D,B 25 F,B 25 G,B 25 H,B 25 J,B 26 B,B 26 D,B 26 F,B 27 B,B 27 C,B 27 D,B 27 F,B 27 G,B 27 H,B 27 J,B 27 K, B 27 L,B 27 M,B 27 B,B 27 N,B 28 B,B 28 C,B 28 D,B 29 B,B 29 C,B 29 D,B 29 K,B 29 L,B 30 B,B 31 B,B 31 C,B 31 D,B 31 F,B 32 B,B 41 B,B 41 C,B 41 D,B 41 F,B 41 G, B 41 J,B 41 K,B 41 L,B 41 M,B 41 N,B 42 B,B 42 C,B 42 D,B 42 F,B 43 K,B 43 L,B 43 M,B 44 B,B 44 C,B 44 D,B 44 F,B 60 B,B 60 C,B 60 D,B 60 F,B 60 G,B 60 H,B 60 J, B 60 K,B 60 L,B 60 M,B 60 N,B 60 P,B 60 Q,B 60 R,B 60 S,B 60 T,B 60 V,B 61 B,B 61 C,B 61 D,B 61 F,B 61 G,B 61 H,B 61 J,B 61 K,B 61 L,B 62 B,B 62 C,B 62 D,B 62 H, B 62 J,B 62 K,B 62 L,B 62 M,B 63 B,B 63 C,B 63 G,B 63 H,B 63 J,B 64 B,B 64 C,B 64 D,B 64 F,B 64 G,B 65 B,B 65 C,B 65 D,B 65 F,B 65 G,B 65 H,B 66 B,B 66 C,B 66 D, B 66 F,B 67 B,B 67 C,B 67 D,B 68 B,B 68 C,B 68 F,B 68 G,B 81 B,B 81 C,B 82 B,C 21 B,C 21 C,C 21 D,C 22 B,C 22 C,C 22 F,C 22 K,C 23 C,C 23 D,C 23 F,C 23 G,C 25 B, C 25 C,C 25 D,C 25 F,D 01 B,D 01 C,D 01 D,D 01 F,D 01 G,D 01 H,D 02 G,D 02 H,D 02 J,D 03 C,D 03 D,D 03 J,D 04 B,D 04 C,D 04 D,D 04 G,D 04 H,D 05 B,D 05 C,D 06 B, D 06 C,D 06 F,D 06 G,D 06 H,D 06 J,D 06 L,D 06 M,D 06 N,D 06 P,D 06 Q,D 07 B,D 21 B,D 21 C,D 21 D,D 21 F,D 21 G,D 21 H,D 21 J,E 01 B,E 01 C,E 01 D,E 01 F,E 01 H, E 02 B,E 02 C,E 02 D,E 02 F,E 03 B,E 03 C,E 03 D,E 03 F,E 04 B,E 04 C,E 04 D,E 04 F,E 04 G,E 04 H,E 05 B,E 05 C,E 05 D,E 05 F,E 05 G,E 06 B,E 06 C,E 21 B,E 21 C, E 21 D,E 21 F,F 01 B,F 01 C,F 01 D,F 01 K,F 01 L,F 01 M,F 01 N,F 01 P,F 02 B,F 02 C,F 02 D,F 02 F,F 02 G,F 02 K,F 02 M,F 02 N,F 02 P,F 03 B,F 03 C,F 03 D,F 03 G,F 03 H, F 04 B,F 04 C,F 04 D,F 04 F,F 15 B,F 15 C,F 15 D,F 16 B,F 16 C,F 16 D,F 16 F,F 16 G,F 16 H,F 16 J,F 16 K,F 16 L,F 16 M,F 16 N,F 16 P,F 16 S,F 16 T,F 17 B,F 17 C,F 17 D, F 21 H,F 21 K,F 21 L,F 21 S,F 21 V,F 21 W,F 21 Y,F 22 B,F 22 D,F 22 G,F 23 B,F 23 C,F 23 D,F 23 G,F 23 H,F 23 J,F 23 K,F 23 L,F 23 M,F 23 N,F 23 Q,F 23 R,F 24 B,F 24 C, F 24 D,F 24 F,F 24 H,F 24 J,F 25 B,F 25 C,F 25 D,F 25 J,F 26 B,F 27 B,F 27 D,F 28 B,F 28 C,F 28 D,F 28 F,F 28 G,F 41 A,F 41 B,F 41 C,F 41 F,F 41 G,F 41 H,F 41 J,F 42 B, F 42 C,F 42 D,G 03 B,G 03 C,G 03 D,G 03 F,G 03 G,G 03 H,G 04 B,G 04 C,G 04 D,G 04 F,G 04 G,G 05 B,G 05 D,G 05 F,G 05 G,G 07 B,G 07 C,G 07 D,G 07 F,G 07 G, G 08 B,G 08 C,G 08 G,G 09 B,G 09 D,G 09 F,G 09 G,G 10 B,G 10 C,G 10 D,G 10 F,G 10 G,G 10 H,G 10 K,G 10 L,H 01 B,H 01 C,H 01 F,H 01 G,H 01 H,H 01 J,H 01 K, H 01 M,H 01 P,H 01 Q,H 01 R,H 01 T,H 02 B,H 02 G,H 02 H,H 02 J,H 02 K,H 02 M,H 02 N,H 02 P,H 03 B,H 03 C,H 03 D,H 03 F,H 03 G,H 03 H,H 03 J,H 03 K,H 03 L,H 03 M, H 04 B,H 04 H,H 04 J,H 04 K,H 04 L,H 04 M,H 04 N,H 04 Q,H 04 R,H 04 S,H 05 B,H 05 C,H 05 F,H 05 G,H 05 H

Figure 1. Star Scientists and Engineers Increase the Probability of Firm Entry into New Technologies
Relative Probabilities with Different Numbers of Active Stars, All Other Variables = Mean Values

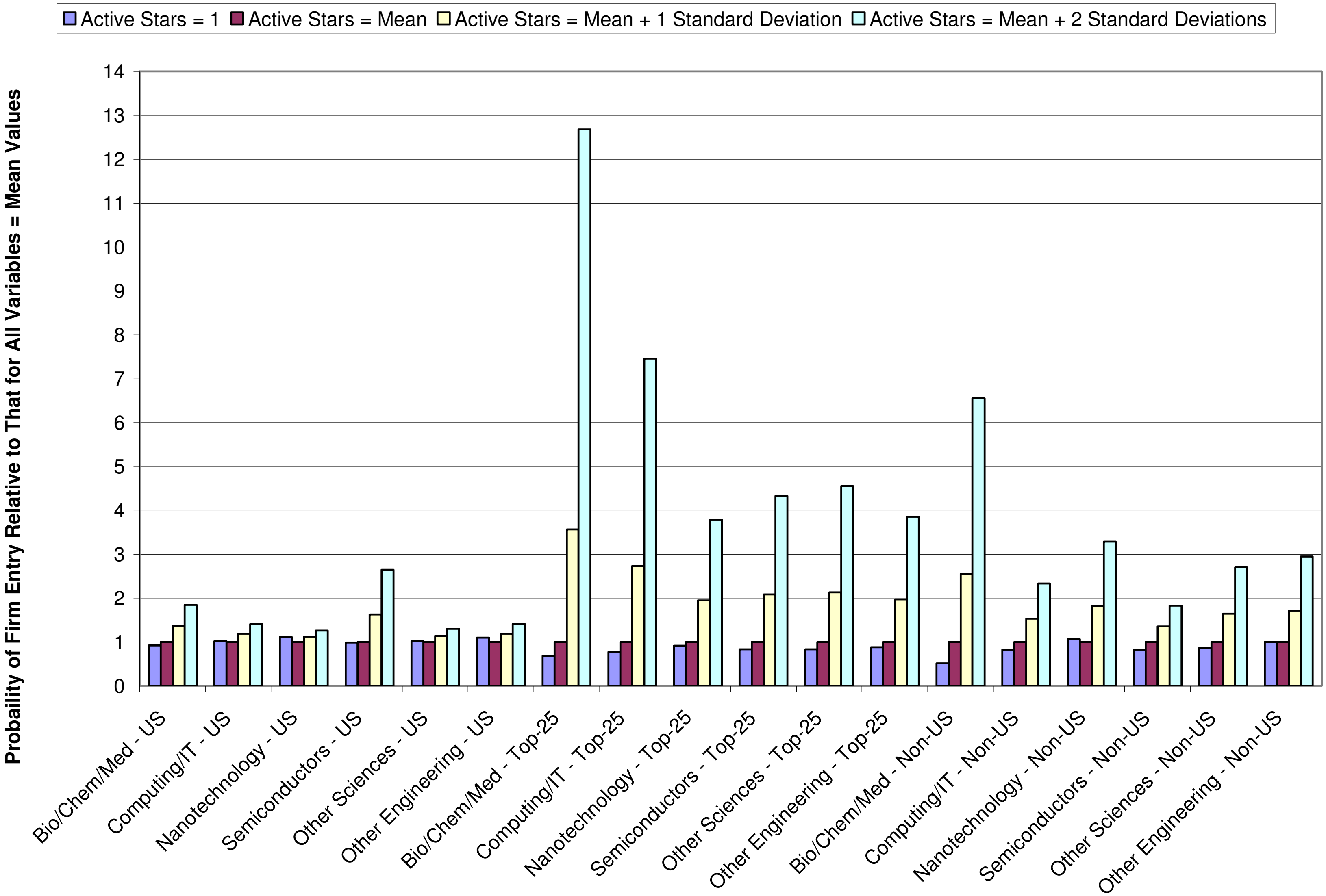
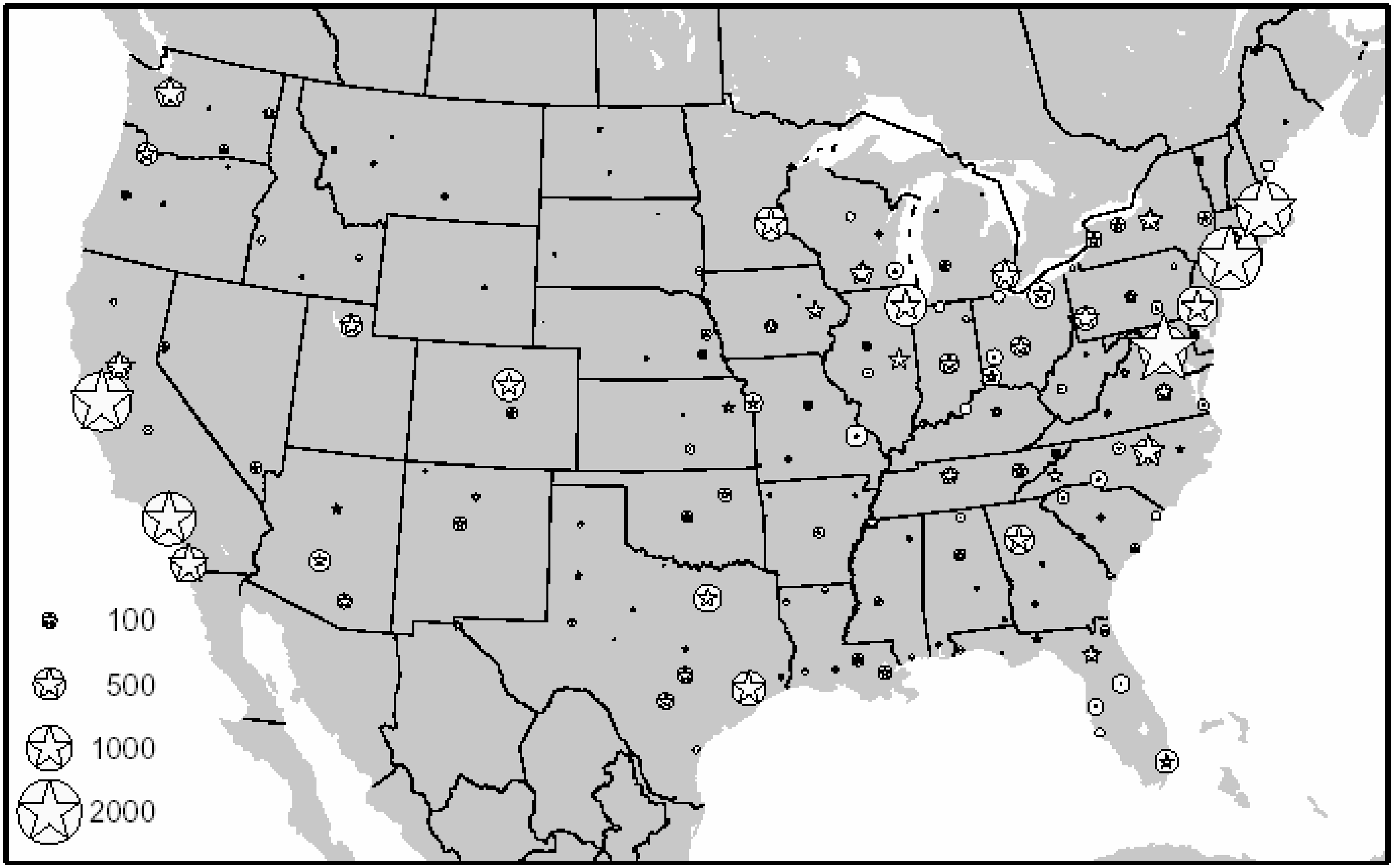
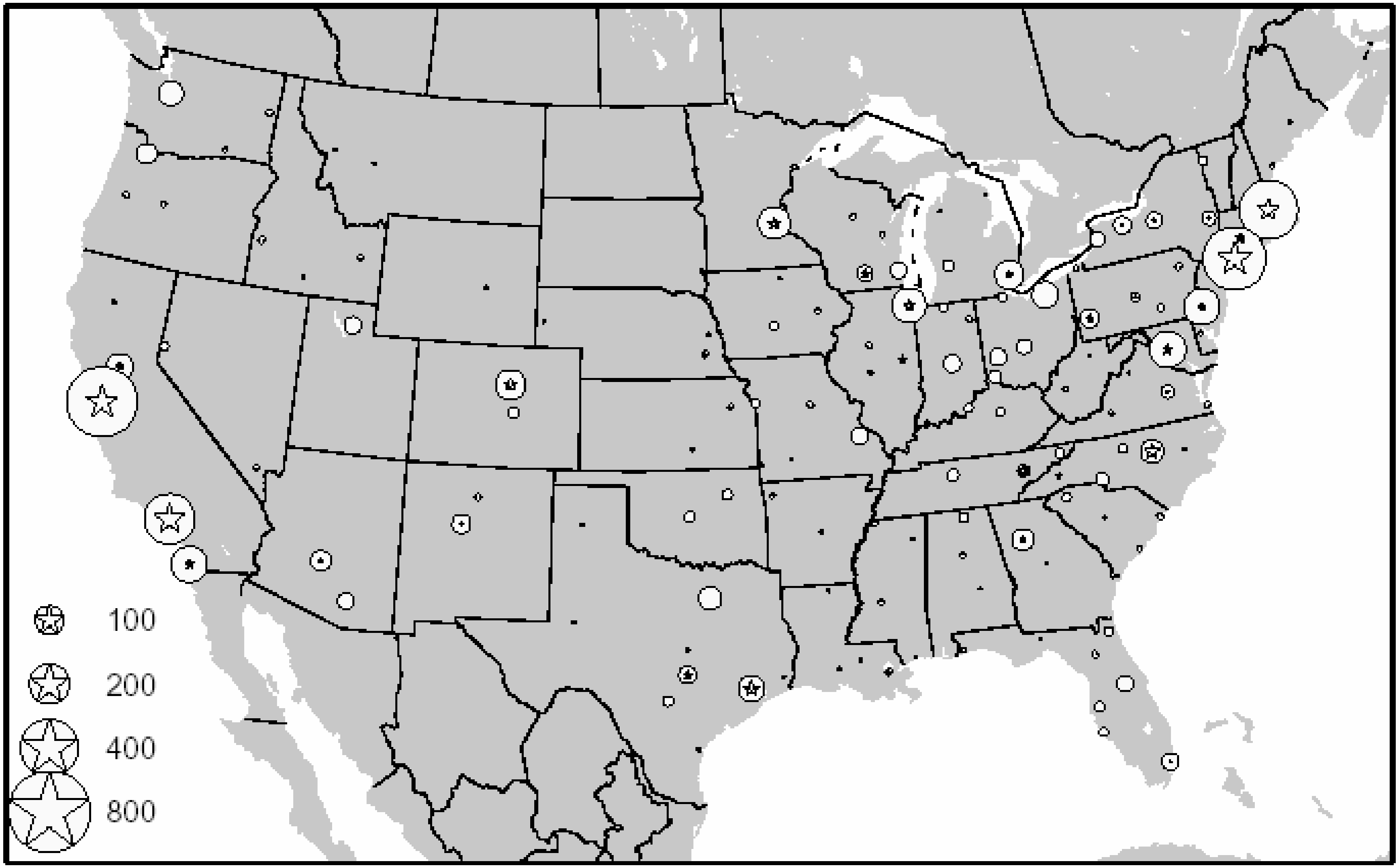


Figure 2. Biology/Chemistry/Medicine Star Scientists & Firm Entry, U.S. Regions, 1981-2004



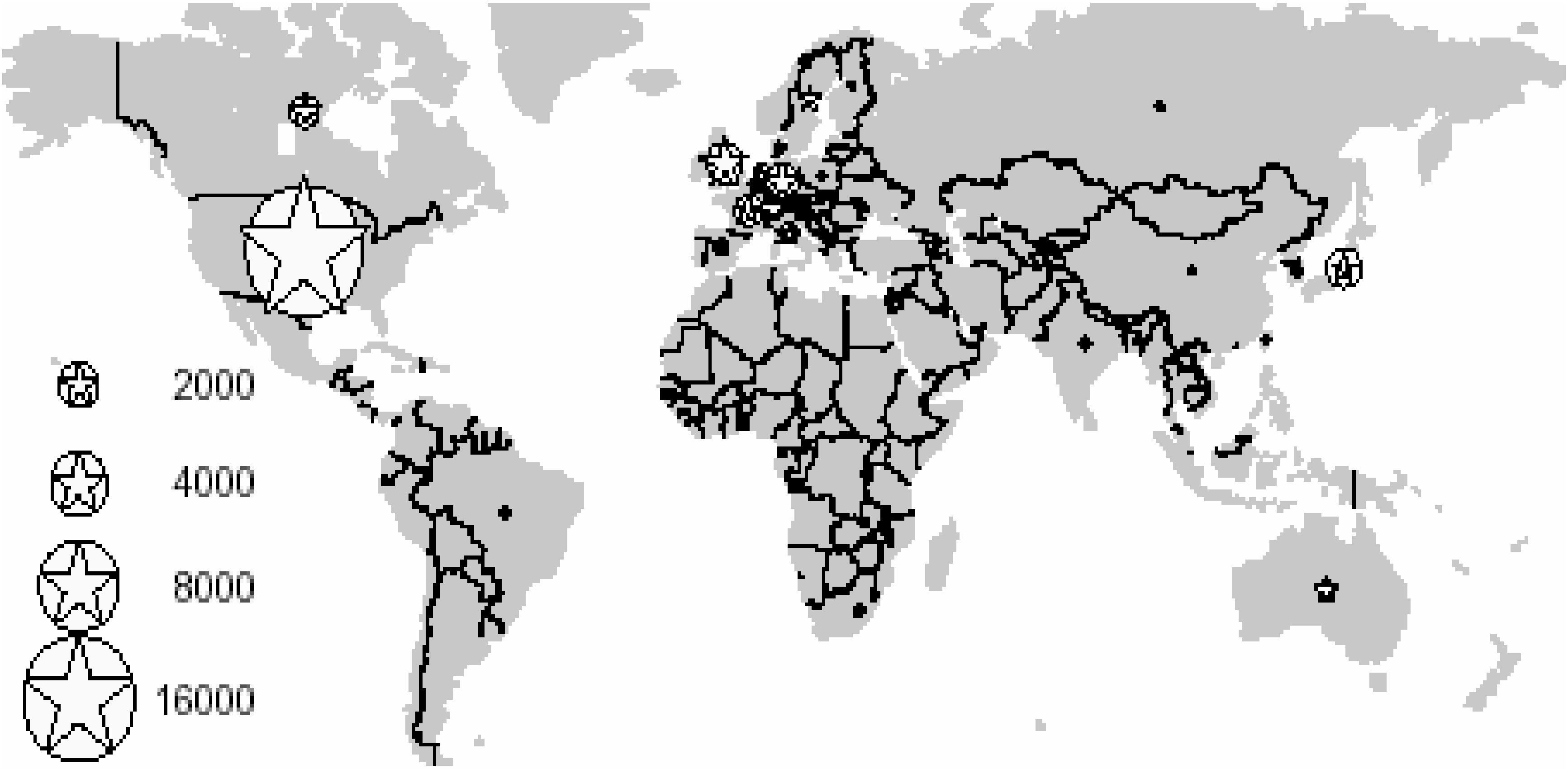
Note: Map to be professionally drawn for next draft.

Figure 3. Nanoscale Science and Technology Star Scientists & Firm Entry, U.S. Regions, 1981-2004



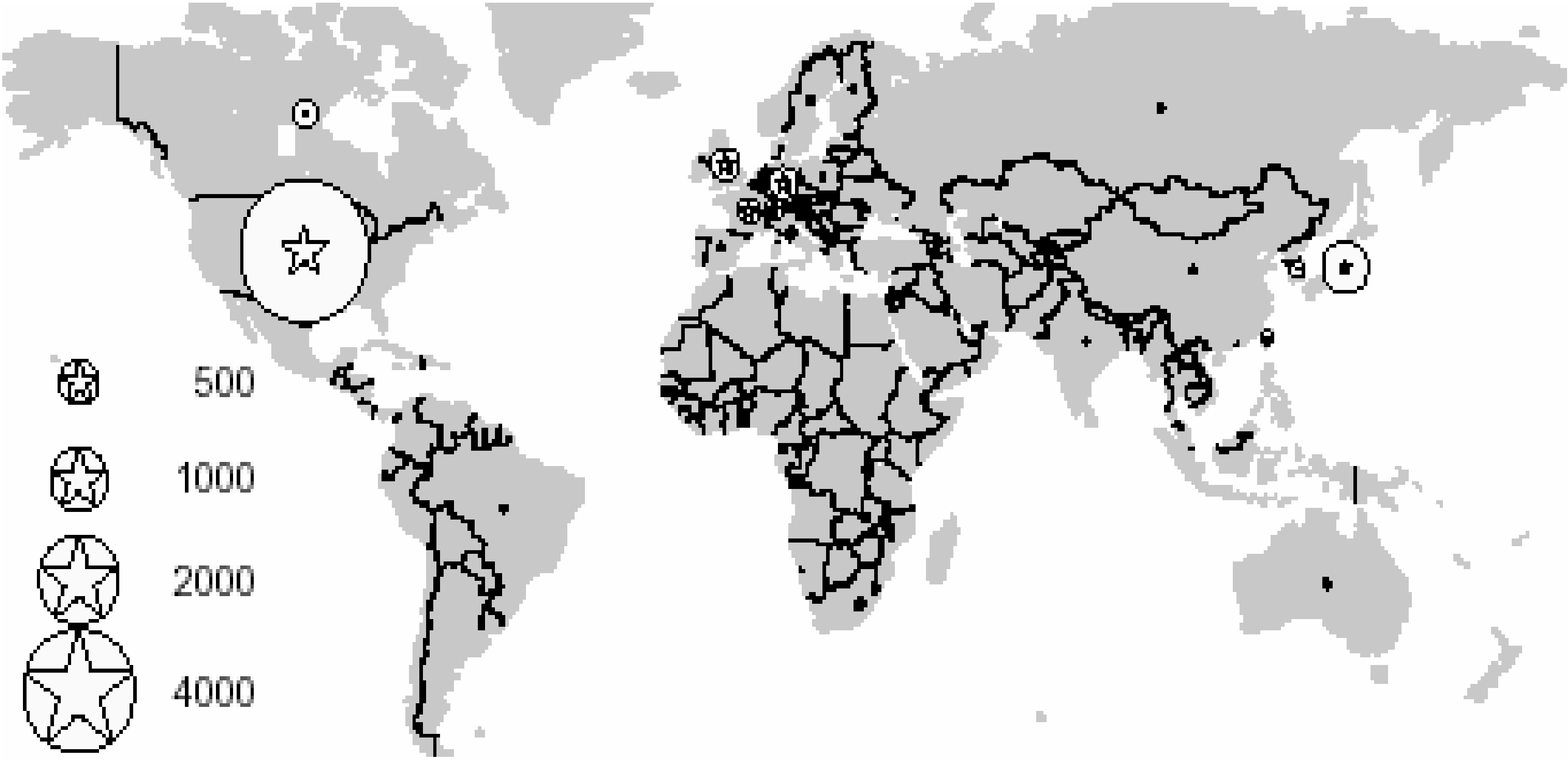
Note: Map to be professionally drawn for next draft.

Figure 4. Biology/Chemistry/Medicine Star Scientists & Firm Entry, U.S. Regions, 1981-2004



Note: Map to be professionally drawn for next draft.

Figure 5. Nanoscale Science and Technology Star Scientists & Firm Entry, 25 Countries, 1981-2004



Note: Map to be professionally drawn for next draft.