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SCIENCE, KNOWLEDGE, AND FIRMS IN DEVELOPING ECONOMIES

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### **ABSTRACT**

Among the top-25 science and technology (S&T) countries, new and diversifying firms are more likely to enter high-technology industries in the 6 developing countries (like the 19 rich countries) in S&T fields where there are star scientists and high numbers of university articles. Stars agglomerate over time, concentrating where there are relatively many peers, aside from a reverse brain drain of foreign-born American stars returning home. University articles diffuse, becoming more equally distributed over time. These star innovators are more likely to begin publishing and/or patenting in a S&T field, country, and year where there are already more stars. However, the developing countries have been able previously to develop or recruit seed cadres of stars in particular S&T fields leading to both more stars and to firms in those fields. We propose viewing an initial phase of low-wage routine production in particular high-tech industries as an investment in joining and ultimately competing equally in that global industry.

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# **Science, Knowledge, and Firms in Developing Economies**

Lynne G. Zucker and Michael R. Darby

In a series of articles, we and our co-authors have provided evidence that across the spectrum of science and technology areas, 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, 2006b, 2006c; Zucker, Darby, and Brewer 1998; Zucker, Darby, and Armstrong 1998, 2002; Darby and Zucker 2001, 2006a). In this paper we focus on the question of whether star scientists play a similar role in developing economies as opposed to the conventional wisdom that those nations’ successes in high-technology industries follow a different model based on imported innovations and low wages. The latter view is certainly more comfortable for those of us in the richer nations, but this paper presents evidence that in fact local star scientists play a key role in determining where and when new or existing firms enter a new area or technology. Furthermore, nations which are fortunate or wise enough to develop or attract a significant cadre of star scientists in a field are likely to see their numbers (and impact) grow over time, through such phenomena as reverse brain drain from the richer nations, especially the United States.

Zucker and Darby (2006c) reports initial empirical results based on the Zucker-Darby Science & Technology Agents of Revolution (STAR) database which will soon permit analysis at the level of individual scientists and engineers and/or firms or other organizations across all countries and high technologies. The STAR database integrates the ISI Web of Science, U.S. Patents, NSF and NIH grants, and various firm and other organization databases using an advanced matching technology to assign a unique identifier to individuals and organizations wherever they appear within and across the constituent databases. Since the matching is still in progress, Zucker and Darby

(2006c) and this paper focus on the 5,401 scientists and engineers identified in ISIHighlyCited.com<sup>SM</sup>, one or more of whom are credited with authorship of some 520,839 articles that appear in the *ISI Web of Science*<sup>®</sup> database. We take membership in the top-250 (based on citations over a rolling 20-year window) in one of the 19 ISI science or engineering fields as a working definition of a star.<sup>1</sup>

Although our data cover all countries, computational considerations led us to limit our analysis data set for this paper and Zucker and Darby (2006c) to the 25 top science and engineering countries defined as all countries that accounted for at least 0.5% of all ISI articles or at least 0.1% of all U.S. patents granted, 1976-2004, or both, with articles prorated by authors' addresses and patents prorated by inventors' addresses. 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 99.2% of U.S. patents. Of these, the non-OECD members (Brazil, China, Israel, India, Taiwan, and USSR/Russia) comprise our working definition of developing countries, while the rest are defined as developed countries. We are aware that these six countries are not a representative sample of developing countries, but believe that they are sufficiently interesting themselves and as a guide to future research. Zucker and Darby (2006c) focuses on an analysis of 179 U.S. regions (functional economic areas) and then moves to comparison with analyses based on either all 25 countries or the 24 non-U.S. countries.

The paper is organized as follows: 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  $\lambda$  that a firm will begin to use a given type of new technology through birth or change in focus in a particular country 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  $\lambda$  is assumed to vary across nations and years according to  $\log \lambda = x\beta$  where  $x$  is a row vector of the explanatory variables and  $\beta$  is a parameter vector to be estimated.<sup>2</sup> In our previous work the significant explanatory variables have been primarily measures of the knowledge base in a region or nation and of its 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 operationalize the concept of star scientist and engineers as those 5,401 very productive authors profiled in ISIHighlyCited.com<sup>SM</sup> across the range of science and engineering topics covered in the Science Citation Index. By including the number of these stars active in a nation

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  $\lambda$ , 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 entry of stars – defined as their first appearance as an author on an article or an inventor on a patent in a given country in one of six broad science areas. They may enter because they have never been an author or inventor before, because they have done so in one or more other countries but not the given one before, or because they have never previously written or invented in a given science area in the country – as when a chemist or physicist begins working in nanotechnology. We expect that measures of a country’s knowledge base rather than economic geography are the dominant determinants of where and when stars enter.

## **II. Empirical Methodology**

Our empirical analysis focuses, in turn, on entry of firms and of stars over time and across 6 science and technology areas and 25 countries. The data bases for this study and Zucker and Darby (2006c) 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*, *High Impact Papers*, and *ISI Highly Cited* of the Institute for Scientific Information<sup>®</sup>, Inc. (ISI<sup>®</sup>, 2005, 2006). 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. The constituent databases are integrated in the Science & Technology Agents of Revolution (STAR) database.

Although the STAR database covers all countries, computational considerations led us to limit our analysis to the 25 top science and engineering countries defined as all countries that accounted for at least 0.5% of all ISI articles or at least 0.1% of all U.S. patents granted, 1976-2004, or both, with articles prorated by authors' addresses and patents prorated by inventors' addresses. These "top-25 science and technology (S&T) countries" were listed in the introduction above together with their breakdown by OECD membership.

These data are used to create an analysis data set containing data from 1981 through 2004 for each of top-25 science and engineering countries. This longitudinal (panel) data set consists of 25 countries x 24 years = 600 observations. Some analysis is done for the OECD and non-OECD subsets of countries, with 456 and 144 observations, respectively. The variables contained in the analysis data set and their summary statistics are listed in Table 1. Their construction is described immediately below.

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 organization name appearing in the assignee-at-issue field of a patent is categorized as a firm, a university, or put in a miscellaneous other category which includes governmental organizations and research institutes. If a patent has  $n$  assignees, where  $n \geq 1$ , each assignee is assigned  $1/n$  for that patent. Organization names appearing in research address or reprint address fields of ISI articles are similarly grouped. Articles that have reported affiliations in the research address field are assigned to those organizations, with each organization getting  $1/m$  credit for that article, where  $m$  is the number of research addresses reported. Those without a research address are assigned to the organization reported in the reprint address, provided that one exists.

#### 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 (Zucker, Darby, Furner, Liu, and Ma 2006). 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 five science and technology areas other than nanotechnology.

#### 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. That concept has been generalized to other cases of obvious linkage between development in science and in high technology, such as nanotechnology (Darby and Zucker 2006) and stem cells (Zucker and Darby 2006a). Star scientists previously have been empirically identified by field specific definitions which pick out a highly productive group comprising on the order of 0.5-1.0 percent of all scientists authoring any papers in the field of interest. The *ISIHighlyCited.com* website offers a database of 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 curricula vitae, (potentially) full listings of publications, and links where

available to the full bibliographic information indexed in the *ISI Web of Science*<sup>®</sup>. Since data quality depends on the cooperation of the highly cited authors, data quality varies with many missing values. Nonetheless, the database seems to offer a comprehensive list of top researchers across the breadth of science and engineering and the research reported here largely validates its usefulness as an empirical tool for identifying star scientists.

Altogether we thus identify 5,401 star scientists, one or more of whom are credited with authorship of some 520,839 articles that appear in the *ISI Web of Science*<sup>®</sup> database. If we count articles each time a star scientist appears, there are 571,068 article authorships. For a sizeable minority (2,042 or 37.8%) of these stars, exactly 10 ISI articles are listed as their full publication list – apparently representing those listed on an NSF or NIH abbreviated vita or supplied by ISI itself.<sup>3</sup> On completion of our person-matching project for all ISI article authors and U.S. patent inventors since 1981, we will be able to add to that article count, but we have not done so at this point. The articles are used to identify where the stars are active based on those 299,583 cases (52.5% of the star authorships) where their affiliation is unambiguous because they are the corresponding author, the sole author, or there is only 1 listed corresponding or research address for a journal that reports multiple addresses on other articles in the same year.<sup>4</sup>

We have used these addresses to identify each country in which these star scientists were active 1981-2004. We code the stars as active in a country 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.

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 not a major concern in practice: the average number of stars per year across all countries, areas, and years is only 5,038 or 33.3% more than the 3,780 average number of unique individuals per year. 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 of publications with a firm-affiliated author or patents assigned to the firm at the time the patent is granted (assignee at issue). Appearance is dated by article publication or patent application date. Firm location corresponds to the address given on the article or the country of each inventor on a patent (for over 89% of patents there is only one country). A particular firm can enter each time it first publishes or patents in a given technology area in a given country. In practice, the vast majority of firms publish and/or patent in only a single area and single country 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 and are not used in the construction of any of the independent variables for the empirical analysis.

Even if they are also a principal in a firm, star scientists generally give their affiliation as a university or research institute. However, we have found star collaborations with firm employees to be particularly powerful indicators of future firm success. There were 38,100 articles authored by stars either with or as firm employees – 7.3% of all stars’ articles. However, only 3,291 stars – 59.6% of all stars – ever had any articles as or with firm employees.

When it comes to establishing property rights to their inventions, however, 28,827 or 63.3% of stars’ patents have a firm listed as or among the assignees at issue out of their 45,542 total U.S. patents.<sup>5</sup> In contrast, only 5,040 or 11.1% have a university listed as or among the assignees at issue. The number of stars listed as inventors on one or more patents was 2,771 of which 1,976 (71.3% of those with any patents) had one or more patents with a firm listed as or among the assignees at issue. However, 1,354 of the stars with firm-assigned patents also had articles linked to firms, so patents identify only 622 additional stars with some firm involvement.

A total of 3,913 stars (72% of all stars) have been identified to have some relationship to a firm at some point in their career, which may range from arms length patent transfer or collaboration with an employee through consulting, advisory or principal role to employment and/or ownership. Of this total, 84.1% can be identified by co-publication, 50.5% by patent assignment, with a 34.6% overlap identified by both ( $84.1\% + 50.5\% - 34.6\% = 100.0\%$ ).

Zucker and Darby (2006c) exploited the comprehensive set of all firms involved in nanotechnology based upon archival data being developed for NanoBank.org to validate our method of detecting firm entry. As shown there, the results are nearly identical for nanotechnology whether we use our publishing/patenting measures of entry or those derived from archival data.

#### II.A.4. Star Entry

Although the main focus is on firm entry, we also analyze the determinants of star entry in a particular country and science area. This is simply defined as the first appearance of a particular star in that country and science area as an author or inventor. As remarked above, this may reflect the star's first appearance anywhere or else geographic or science-area change.

#### II.A.5. Knowledge Stocks

We used three separate sources to develop measures of the non-firm science base by 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 on 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.

With firm observations excluded, all the articles and patents used in these variables can belong to either universities or "other" organizations (such as national labs or research institutes). In case of multiple organizational affiliations for an observation (due to the presence of multiple research addresses for articles or multiple assignees for patents), each organization is credited with the corresponding fractional amount for that observation. For example, if a patent (article) has listed 1 university and 1 national lab as assignees (research addresses), each is credited  $\frac{1}{2}$ , so only 0.5 is added to the university patent (article) total for the corresponding total.

Patents are dated by the application date so this variable suffers truncation both due to patents that are applied for but only granted after the end of the period. We deal with this in the estimation procedure.

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

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

where  $K_{i,t}$  is the knowledge stock of type  $i$  (denoting science and technology area and country) at time  $t$  and  $I_{i,t}$  is the input series for this knowledge stock – alternatively counts by 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.<sup>6</sup>) These science and technology area counts are then allocated to countries with each research address or assignee address receiving equal credit.<sup>7</sup> 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 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, country, and year.

#### II.A.6. Other Variables

The employment data 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](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  $\lambda$ . However, overdispersion (variance  $>$  mean) will be observed if there is unobserved heterogeneity across observations. This is frequently dealt with by assuming that the parameter  $\lambda$  is distributed according to

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

where the disturbance term  $\varepsilon$  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  $\lambda$  and variance  $\lambda + \alpha^{-1}\lambda^2$  where  $\alpha$  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.,  $\varepsilon$  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.

As noted above, there is potential truncation bias in several of the variables. We found that this affected only the last three years of the sample and accordingly include dummy variables for each of these years as a straightforward way of dealing with this problem.

### **III. Empirical Results**

This section discusses our empirical results for both firm entry (III.A) and star entry (III.C). 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 intervening subsection III.B examines whether the major determinants in these regressions are becoming more diffuse or more concentrated over time, motivating our analysis of star entry.

#### **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 top-25 science and technology countries data set, Table 3 for the 19 OECD members among these 25 countries, and Table 4 for the 6 OECD non-members among these 25.

For the 25-countries results in Table 2, the number of star scientists and engineers active in a region or country has positive and significant effects on the probability of a firm entering in all six science and technology areas. The university articles knowledge stock has positive coefficients which are significant at the 5 percent level in three cases or at the 10 percent level in

four of the six cases. The high-impact articles and university-patents knowledge stocks have negative signs in all but one case and most of those are statistically significant. We interpret these findings as indicating that the stars are personally involved in causing a substantial amount of firm entry. Because we first identified them by their scientific publications, we have always referred to these individuals as star scientists, but it is truer to their great energy expressed in a multiplicity of talents and roles to call them star innovators.

There is some evidence that nearby firms have an advantage in exploiting the stars' and their colleagues' potentially disembodied discoveries as measured by university articles, but this may also be capturing personal involvement of other professors not identified by our star measure. The negative signs for high-impact articles and university patents are puzzling, and may be an artifact of relatively high correlation among high-impact articles, university articles, and university patenting. An ex post hypothesis would be that a particularly rich vein of research can lead to postponement of firm founding. Further research on the interaction of university research and firm entry is clearly warranted, and we should note that Zucker and Darby (2006c) report inconsistent sign patterns for high-impact articles, university articles, and university patenting in similar regressions for U.S. regions.

In those U.S. regional regressions in Zucker and Darby (2006c), both employment (as a measure of size) and average wage (as a measure of labor-force quality) have significantly positive effects on the probability of firm entry in every science and technology area. We were unable to find a reasonably comparable measure of average wage for all 25 countries, so we dropped it from the regressions reported here and obtained mostly negative signs (only one significant) on employment. However, in Table 3 for the OECD members separately, the coefficients on employment are again positive and significant in every case. In Table 4 for

OECD non-members, the employment coefficients are negative and significant in every case. We conclude that the huge size of China and India and their relative inhospitability to firm formation over the sample period as a whole accounts for this sign pattern. Alternatively, the employment sign pattern can be analyzed more formally as reflecting omitted-variable bias due to the negative correlation between average wages (for which data is lacking) and population or total employment. This negative correlation is strongest in the case of the 6 non-OECD members and the lower wage effect dominates the pure size effect.

The pattern of coefficients on the dummy variables for 2002, 2003, and 2004 reflect the waning effect of truncation bias moving from 2004 to 2002. In experiments not reported in the tables, we found that additional year dummies had no significant coefficients.

With the exception of the employment variable already discussed, the results in Table 3 for the OECD countries separately are qualitatively identical to those in Table 2 for all top-25 science and technology countries, so the characterization of those results is unchanged. In contrast, there is some evidence of a complementary process working in the developing countries subset in Table 4. Stars and university articles continue to have a positive impact although they are mostly no longer statistically significant in the catch-all categories of other sciences and other engineering. In addition, the university-patents knowledge stocks have positive and significant coefficients for two (5% level) or three (10% level) science and technology areas.

The strongly positive coefficients (with one exception) on university articles and the weaker evidence for university patenting could be interpreted as supporting the conventional wisdom that these developing economies are indeed an attractive source of low-wage technically competent personnel for outsourcing routine technical tasks, but not significant competitors for the richer countries in terms of creativity and innovation. Li (2006) has recently done a detailed

case study of the development of the Taiwanese computer industry from routine outsourcing to the globally dominant designer and manufacturer (primarily in their Chinese plants) of laptop computers. Her analysis – and the significant positive star coefficients for biology/chemistry/medicine, computing/information technology, nanotechnology, and semiconductors in Table 4 – argue that this view is unduly complacent from the point of view of the richer countries high-tech industries and unduly pessimistic from the point of view of the potential of the developing economies. In past decades, stars who were literally born in the developing countries have emigrated to the richer ones (often while in graduate school) and driven new firm and even industry formation there, particularly to the benefit of the United States. These star innovators are still attracted to their home countries and when incentives are attractive and other stars in their field are there, they can and do return home (perhaps with dual residences and citizenships) quickly driving an increased pace of firm formation and development in particular industries. Sections III.B and III.C focus on that process.

Before leaving the results on firm entry, it is important to note several robustness tests reported in the companion paper Zucker and Darby (2006c). First, as mentioned previously, the results are nearly identical for nanotechnology whether our publishing/patenting measures of entry or those derived from archival data NanoBank.org are used. We also tried excluding all firms for which entry is identified by an article or inventor and also obtained very similar results. Experiments with raising the hurdle to qualify as a star so as to exclude two thirds of the ISI Highly Cited Authors actually strengthened the results.

### **III.B. Concentration or Diffusion of Stars and Knowledge**

This section addresses the question of whether the distributions of high-technology firm entry and its determinants are becoming more or less concentrated over time. That is, is there a tendency toward geographic agglomeration or diffusion? A simple statistic summarizes the panel data for a variable in this regard: the correlation coefficient for the level of the variable and its growth rate. A positive value indicates that the areas with larger values tend to grow disproportionately faster while those with smaller values grow disproportionately slowly or even shrink – that is, the variable is agglomerating. In contrast, a negative correlation coefficient means that areas with smaller values have above average growth rates while the areas with larger values are growing more slowly or shrinking – diffusion. The more closely the correlation coefficient approaches 1 in absolute value, the more certainly is size an accurate predictor of disproportionate growth.

Table 5 reports these correlation coefficients for stars and the three knowledge stocks. For all 25 countries taken together and the 19 OECD members as a group, there is no significant tendency toward agglomeration or diffusion with respect to these variables with one major exception: University articles are showing significant diffusion over time with those countries which have traditionally put less emphasis on publishing tending to catch up with the traditional scientific powerhouses. This catch-up trend is seconded by a general if at best marginally significant tendency toward diffusion of high-impact articles. For the OECD non-members, however, the situation is more complicated. The same tendency for diffusion is present for university articles, but there also appears to be strong forces of agglomeration for stars in four of the six science and technology areas and, instead in computing/information technology, for high impact articles and university patents.

At first it seems odd that stars show agglomeration only for the non-OECD members. The last two parts of Table 5 for the 18 OECD members other than the U.S. and for the 179 functional economic regions of the U.S. attempt to explain what is going on. The U.S. regions look much like the OECD non-members with clear forces of agglomeration operating for the stars and clear forces of diffusion for the university articles. To some extent that is true also for the non-U.S. OECD members although only two of the star correlation are significantly positive. These 18 countries also show stronger diffusion among themselves in high-impact articles than is present in the U.S. and all-19-OECD-member samples. The reason that star agglomeration is weaker when the U.S. is included in the sample is because there is a significant countercurrent – or reverse brain drain in the popular terminology – of star academics returning from top U.S. universities to top universities in their non-OECD-member homelands. Aside from this special case, stars tend over time to be born or move to where there are already more stars as documented in Section III.C.

### **III.C. Entry of Stars**

Since stars seem to play an important role in determining commercial as well as scientific development, we experimented with applying the same sort of models used for firm entry to explain star entry. This is only meant to be a first look at the data in the hope of interesting others in the next steps in this research program. The results of these experiments are reported in Tables 6, 7, and 8.

For all six science and technology areas and for all three samples the number of stars already in a country has a positive impact on the entry of stars that is significant at the 0.1 percent level or better. This strong result would certainly undergird the general tendency toward

star agglomeration just discussed. Unlike the firm entry equations, university articles seem to have no effect on star entry. More puzzling is the general (but not always and not always significant) pattern of negative coefficients on both the high-impact articles and university patents knowledge stocks. We had expected the opposite, at least for high-impact articles. We must leave this puzzle for future research although we have come up with a possible rationalization: Doctoral students with disappointing placement are sometimes advised to write (and invent?) so much that they will earn an offer to move to a better university. Could it be that places with high number of high-impact articles and university patents relative to their number of stars have a few overachieving stars determined to leave?

#### **IV. Conclusions**

We have provided evidence that star scientists and engineers – or better star innovators – are driving forces for high-technology firms as well as science and that this is true in both the OECD world and in a set of less fortunate economies. We have also seen that more stars tend to be born or move to where there are already more stars. We can speculate on whether that tendency reflects a need of these special people for intellectual playmates or instead simply persistence in conditions that are relatively conducive to raising or attracting these individuals. We hope that we have made the case that research on this question can have important implications for growth and development.

A colleague remarked that our results seem to show that the have-nots will never get, but we believe that this is a faulty interpretation. First, note that the explanatory power of our star-entry regressions is relatively low for the OECD non-member countries, implying a larger role

for the omitted variables, including the ones that determine which of these countries somehow give birth or create a seed cadre of stars in a field who can then create more of their numbers and attract stars from other countries, particularly in recent years from the U.S. The fact is that some universities do make a successful group offer to stars who might otherwise never come there singly, creating a new center of excellence on their campus. If the conditions are right, that university might be in a developing country. We leave it to future research to uncover the meaning of “the conditions are right.”

Historically poor immigrants to the U.S. or those without American licenses to practice their professions have endured or invested in a period of menial jobs while developing the skills and credentials needed to compete in the American marketplace. Typically it takes about 10 to 15 years for immigrants from non-English-speaking countries to catch up with the earnings of American-born workers with the same education. Perhaps this provides a model for understanding the initial phase of low-wage, routine production where developing countries get their start in high-technology fields. This phase can be an investment in joining and ultimately competing successfully in the global marketplace, not a permanent second-class membership.

## **Appendix A**

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 are listed in Table A.1.

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## Footnotes

<sup>1</sup> Specifically, we excluded highly cited authors from ISI's Economics & Business and Social Sciences–General categories and used those from the remaining 19 categories: Agricultural Sciences, Engineering, Neuroscience, Biology & Biochemistry, Geosciences, Pharmacology, Chemistry, Immunology, Physics, Clinical Medicine, Materials Science, Plant & Animal Science, Computer Science, Mathematics, Psychology/Psychiatry, Ecology/Environment, Microbiology, Molecular Biology & Genetics, and Space Sciences.

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

<sup>3</sup> Another 3.2% of the stars are listed as having 5-9 ISI-indexed articles, presumably having cited works in press or conference volumes on the NSF/NIH vita. We dropped entirely from the analysis those 30 highly cited authors out of 5,431 for which there are no ISI-indexed articles listed.

<sup>4</sup> ISI article data do not distinguish which address (normally an organization) goes with which author except for a possible single author designated corresponding author who then matches (at least) to the corresponding address). The cases indicated in the text are those for which the star scientist can be definitively located with an address. The 299,583 authorships corresponded to 276,182 different articles, with the difference (23,401) all accounted for by multiple star authors with a single address.

<sup>5</sup> Since we cannot rely on a definitive list of articles from ISI, we performed a name match based on exact match of both the last name and the first name and to the extent they are available middle name or initial. This method probably results in an overestimate of the number of star patents with false positives outweighing missed matches due to misspellings.

<sup>6</sup> 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.

<sup>7</sup> 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 in principle equals the number assigned to it in the 25-country data set. The only differences arise because of a few U.S. observations which were omitted in the U.S.-only data set because we were unable to assign the partial or garbled address to a region.

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

Variables <sup>1</sup>	Top-25 Sci. & Tech Countries					19 OECD Countries in Top-25 Sci. & Tech.					6 Non-OECD Countries in Top-25 Sci. & Tech.				
	N	Mean	S.D.	Min	Max	N	Mean	S.D.	Min	Max	N	Mean	S.D.	Min	Max
<u>Entry of Firms into:</u>															
Biology/Chemistry/Medicine	600	50.3	149.2	0	1067	456	63.4	169.0	0	1067	144	8.5	6.8	0	33
Computing/Information Technology	600	22.2	80.4	0	738	456	27.9	91.4	0	738	144	4.1	5.4	0	32
Nanotechnology	600	14.3	53.6	0	483	456	18.1	61.0	0	483	144	2.1	2.8	0	13
Semiconductors	600	25.0	80.7	0	657	456	31.5	91.6	0	657	144	4.2	4.0	0	20
Other Sciences	600	26.8	88.9	0	609	456	34.0	100.9	0	609	144	3.8	3.9	0	20
Other Engineering	600	82.2	286.2	0	2107	456	104.2	325.2	0	2107	144	12.4	14.1	0	74
<u>Entry of Star Scientists</u>															
Biology/Chemistry/Medicine	600	18.3	78.4	0	1386	456	23.5	89.3	0	1386	144	2.0	2.8	0	24
Computing/Information Technology	600	3.5	15.1	0	228	456	4.3	17.2	0	228	144	0.9	1.8	0	16
Nanotechnology	600	0.4	1.5	0	19	456	0.4	1.7	0	19	144	0.2	0.5	0	3
Semiconductors	600	3.4	14.5	0	240	456	4.2	16.6	0	240	144	0.9	1.2	0	6
Other Sciences	600	2.3	10.2	0	164	456	3.0	11.6	0	164	144	0.4	0.7	0	3
Other Engineering	600	1.4	6.5	0	98	456	1.8	7.4	0	98	144	0.2	0.5	0	2
<u>Star Scientists &amp; Engineers Active</u>															
Biology/Chemistry/Medicine	600	126.2	395.8	0	2385	456	163.7	447.6	0	2385	144	7.4	6.9	0	26
Computing/Information Technology	600	25.4	87.3	0	516	456	31.9	99.2	0	516	144	4.7	7.0	0	26
Nanotechnology	600	3.9	14.6	0	116	456	4.9	16.6	0	116	144	0.7	1.0	0	3
Semiconductors	600	20.7	70.5	0	472	456	26.2	80.1	0	472	144	3.1	2.6	0	12
Other Sciences	600	17.0	57.7	0	361	456	22.1	65.4	0	361	144	0.8	1.0	0	5
Other Engineering	600	8.6	29.3	0	200	456	10.9	33.3	0	200	144	1.1	1.6	0	6
<u>High Impact Articles Knowledge Stock</u>															
Biology/Chemistry/Medicine	600	277.3	834.2	0	4911.6	456	360.3	942.0	0	4911.6	144	14.7	15.5	0	64.4
Computing/Information Technology	600	58.4	162.4	0	1194.3	456	72.9	183.8	0	1194.3	144	12.4	15.6	0	123.6
Nanotechnology	600	15.1	53.7	0	513.1	456	18.5	61.1	0	513.1	144	4.3	7.4	0	45.0
Semiconductors	600	53.4	146.1	0	907.9	456	67.0	165.2	0	907.9	144	10.1	8.7	0	32.9
Other Sciences	600	96.7	324.2	0	1994.1	456	125.2	367.4	0	1994.1	144	6.2	5.6	0	19.9
Other Engineering	600	30.4	91.2	0	528.3	456	39.2	103.1	0	528.3	144	2.3	2.1	0	8.5
<u>University Articles Knowledge Stock</u>															
Biology/Chemistry/Medicine	600	46272.6	108860.9	64.0	729673.6	456	57463.7	122712.9	64.017	729673.6	144	10834.2	7940.3	177.8	48549.1
Computing/Information Technology	600	3501.5	7268.2	6.0	49950.6	456	4130.7	8190.5	5.9667	49950.6	144	1509.0	1602.5	37.3	11506.0
Nanotechnology	600	953.9	2557.6	0	24685.3	456	1097.1	2841.9	0	24685.3	144	500.4	1195.5	0	9289.5
Semiconductors	600	7438.5	13386.2	24.4	81232.2	456	8374.9	15019.5	24.405	81232.2	144	4473.3	4601.0	60.1	29886.5
Other Sciences	600	3245.2	7703.8	3	48111.6	456	3886.8	8723.5	3	48111.6	144	1213.6	999.6	4	4323.2
Other Engineering	600	1534.7	3622.9	1	23672.5	456	1815.7	4104.6	1	23672.5	144	644.8	570.5	7.3	3235.9
<u>University Patents Knowledge Stock</u>															
Biology/Chemistry/Medicine	600	134.7	672.2	0	5259.8	456	173.8	767.0	0	5259.8	144	11.0	17.5	0	71.5
Computing/Information Technology	600	11.3	61.0	0	576.3	456	14.6	69.6	0	576.3	144	0.9	2.9	0	25.8
Nanotechnology	600	53.5	334.6	0	3599.1	456	68.5	382.5	0	3599.1	144	5.7	21.6	0	237.4
Semiconductors	600	5.8	28.5	0	294.8	456	7.2	32.3	0	294.8	144	1.2	8.2	0	92.8
Other Sciences	600	34.8	163.4	0	1281.0	456	45.0	186.3	0	1281.0	144	2.4	5.3	0	49.3
Other Engineering	600	62.1	291.6	0	2330.0	456	79.9	332.5	0	2330.0	144	5.9	9.5	0	69.1
Total Employment in Country	600	47.3	123.3	1.0	752.0	456	20.3	28.0	1.935	139.3	144	132.6	227.1	1.0	752.0

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.

Table 2. Firm Entry into New Technologies – Poisson Regressions  
Top-25 Science & Technology Countries, 1981-2004

Explanatory Variables	Science and Technology Areas of Firm Entry					
	Bio/Chem/Med	Computing/IT	Nanotechnology	Semiconductors	Other Sciences	Other Engineering
Star Scientists & Engineers Active in Country in Same S&T Area as Entry	0.0035*** 0.0001	0.0140*** 0.0025	0.0651*** 0.0049	0.0133* 0.0055	0.0192*** 0.0038	0.0254** 0.0081
High Impact Articles Knowledge Stock in Same S&T Area as Entry	-0.0019*** 0.0001	-0.0043** 0.0014	-0.0008 0.0045	-0.0031 0.0027	-0.0036*** 0.0007	0.0024 0.0023
University Articles Knowledge Stock in Same S&T Area as Entry	0.0000*** 0.0000	0.0001^ 0.0000	0.0002*** 0.0001	0.0000 0.0000	0.0002*** 0.0001	0.0001 0.0001
University Patents Knowledge Stock in Same S&T Area as Entry	-0.0010*** 0.0001	-0.0023^ 0.0013	-0.0022*** 0.0005	-0.0034 0.0027	-0.0046*** 0.0006	-0.0019** 0.0006
Total Employment in Country (millions of persons)	-0.0017*** 0.0003	-0.0002 0.0003	0.0004 0.0004	-0.0001 0.0004	-0.0004 0.0003	-0.0001 0.0004
Constant	2.5454*** 0.0532	1.7118*** 0.0728	1.3053*** 0.1304	2.1689*** 0.1192	1.7140*** 0.1169	2.9924*** 0.1118
Dummy = 1 in 2002, else 0	-0.1958^ 0.1113	-0.2609 0.1904	-0.5906*** 0.1098	0.2894 0.1890	-0.3826* 0.1820	-0.4882^ 0.2586
Dummy = 1 in 2003, else 0	-0.3124^ 0.1690	0.4756^ 0.2585	-1.2523*** 0.2036	0.3956^ 0.2110	-0.9073** 0.2691	-0.9040*** 0.2120
Dummy = 1 in 2004, else 0	-2.1357*** 0.5411	-0.7148** 0.2402	-1.6237** 0.5712	-0.1660 0.2171	-2.3861*** 0.5524	-1.5355*** 0.2039
Pseudo R <sup>2</sup>	0.8889	0.8557	0.7737	0.7720	0.8597	0.8589

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 3. Firm Entry into New Technologies – Poisson Regressions  
19 OECD Members in the Top-25 Science & Technology Countries, 1981-2004

Explanatory Variables	Science and Technology Areas of Firm Entry					
	Bio/Chem/Med	Computing/IT	Nanotechnology	Semiconductors	Other Sciences	Other Engineering
Star Scientists & Engineers Active in Country in Same S&T Area as Entry	0.0019*** 0.0003	0.0044*** 0.0009	0.0134** 0.0039	0.0055*** 0.0009	0.0062*** 0.0015	0.0159*** 0.0027
High Impact Articles Knowledge Stock in Same S&T Area as Entry	-0.0008*** 0.0002	-0.0036*** 0.0006	0.0037 0.0032	-0.0028*** 0.0005	-0.0023*** 0.0006	-0.0041*** 0.0010
University Articles Knowledge Stock in Same S&T Area as Entry	0.0000** 0.0000	0.0001*** 0.0000	0.0001*** 0.0000	0.0000^ 0.0000	0.0001** 0.0000	0.0002*** 0.0000
University Patents Knowledge Stock in Same S&T Area as Entry	-0.0005*** 0.0001	-0.0046*** 0.0008	-0.0017*** 0.0003	-0.0082*** 0.0010	-0.0032*** 0.0004	-0.0023*** 0.0003
Total Employment in Country (millions of persons)	0.0181*** 0.0030	0.0376*** 0.0018	0.0357*** 0.0012	0.0422*** 0.0020	0.0353*** 0.0026	0.0388*** 0.0024
Constant	2.5512*** 0.0526	1.0122*** 0.0732	0.4689*** 0.0768	1.4760*** 0.0725	1.2444*** 0.0663	2.2590*** 0.0881
Dummy = 1 in 2002, else 0	-0.3232* 0.1565	-0.4120* 0.1977	-0.4061*** 0.1041	0.1002 0.1142	-0.4837*** 0.1384	-0.6796*** 0.1788
Dummy = 1 in 2003, else 0	-0.4346* 0.2098	0.2918 0.1989	-1.0270*** 0.1617	0.2692^ 0.1512	-0.9721*** 0.2076	-1.0981*** 0.1763
Dummy = 1 in 2004, else 0	-1.4890*** 0.4179	-0.9409*** 0.2626	-1.0411* 0.4172	-0.2886^ 0.1529	-2.1716*** 0.4293	-2.2150*** 0.2354
Pseudo R <sup>2</sup>	0.9057	0.9147	0.9090	0.8888	0.9188	0.9274

Notes: Robust standard errors in parentheses below coefficient estimates. N =456 . 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  
6 OECD Non-members in the Top-25 Science & Technology Countries, 1981-2004

Explanatory Variables	Science and Technology Areas of Firm Entry					
	Bio/Chem/Med	Computing/IT	Nanotechnology	Semiconductors	Other Sciences	Other Engineering
Star Scientists & Engineers Active in Country in Same S&T Area as Entry	0.0347* 0.0165	0.0616*** 0.0158	0.3206** 0.1009	0.0766* 0.0310	0.0155 0.0906	0.1031 0.0662
High Impact Articles Knowledge Stock in Same S&T Area as Entry	-0.0157* 0.0077	-0.0198* 0.0098	0.0194 0.0299	-0.0262* 0.0124	0.0609*** 0.0133	-0.1186** 0.0449
University Articles Knowledge Stock in Same S&T Area as Entry	0.0001*** 0.0000	0.0007*** 0.0001	0.0006^ 0.0003	0.0001*** 0.0000	0.0000 0.0001	0.0007** 0.0002
University Patents Knowledge Stock in Same S&T Area as Entry	0.0134** 0.0044	-0.0015 0.0300	0.0094^ 0.0057	-0.0043 0.0058	0.0126 0.0155	0.0482*** 0.0124
Total Employment in Country (millions of persons)	-0.0016*** 0.0003	-0.0030*** 0.0006	-0.0043* 0.0018	-0.0023*** 0.0005	-0.0014** 0.0005	-0.0021*** 0.0005
Constant	0.8271*** 0.1481	0.3062^ 0.1607	-0.2387 0.1615	0.8455*** 0.1180	0.5669** 0.2034	1.6859*** 0.2270
Dummy = 1 in 2002, else 0	0.1746 0.2462	-0.8480^ 0.4733	-0.0579 0.4138	0.3909* 0.1916	0.6071 0.3799	-0.8750* 0.4005
Dummy = 1 in 2003, else 0	0.3245 0.2126	-0.6470 0.6436	-0.5203 0.6054	0.5541 0.3502	0.3314 0.3593	-1.6475* 0.8061
Dummy = 1 in 2004, else 0	-0.7154* 0.3610	-1.8633** 0.6748	-1.8682 1.4749	-0.3660 0.4645	0.0743 0.3505	-3.3395** 1.1913
Pseudo R <sup>2</sup>	0.2858	0.2284	0.2045	0.2077	0.1247	0.2189

Notes: Robust standard errors in parentheses below coefficient estimates. N = 144. 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. Agglomeration or Diffusion? Correlation Coefficients for the Levels and Growth Rates of Star Scientists & Engineers and the Three Knowledge Stocks

	Correlation Coefficients of Level and Growth Rate across Years and Countries by S&T Field					
	Bio/Chem/Med	Computing/IT	Nanotechnology	Semiconductors	Other Sciences	Other Engineering
<u>Top-25 Science &amp; Technology Countries</u>						
Star Scientists & Engineers	-0.05	0.04	-0.01	0.00	0.02	0.01
High Impact Articles	-0.08 <sup>^</sup>	-0.06	-0.08	-0.05	-0.05	-0.05
University Articles	-0.16 <sup>***</sup>	-0.18 <sup>***</sup>	-0.18 <sup>***</sup>	-0.21 <sup>***</sup>	-0.08 <sup>*</sup>	-0.16 <sup>***</sup>
University Patents	-0.03	-0.02	-0.04	-0.02	-0.04	-0.01
<u>19 OECD Members in Top-25 S&amp;T Countries</u>						
Star Scientists & Engineers	-0.02	0.06	-0.02	0.00	-0.01	0.00
High Impact Articles	-0.08 <sup>^</sup>	-0.07	-0.09	-0.08 <sup>^</sup>	-0.06	-0.05
University Articles	-0.16 <sup>***</sup>	-0.20 <sup>***</sup>	-0.19 <sup>***</sup>	-0.21 <sup>***</sup>	-0.17 <sup>***</sup>	-0.16 <sup>***</sup>
University Patents	-0.03	-0.02	-0.04	-0.03	-0.04	-0.01
<u>6 OECD Non-members in Top-25 S&amp;T Countries</u>						
Star Scientists & Engineers	0.00	0.05	0.67 <sup>***</sup>	0.31 <sup>***</sup>	0.75 <sup>***</sup>	0.42 <sup>***</sup>
High Impact Articles	-0.10	0.22 <sup>**</sup>	-0.08	-0.12	-0.11	-0.12
University Articles	-0.42 <sup>***</sup>	-0.18 <sup>*</sup>	-0.16 <sup>^</sup>	-0.32 <sup>***</sup>	-0.19 <sup>*</sup>	-0.39 <sup>***</sup>
University Patents	-0.07	0.25 <sup>*</sup>	0.17	0.05	0.08	-0.04
<u>18 OECD Countries (Excluding US)</u>						
Star Scientists & Engineers	-0.02	0.06	0.19 <sup>**</sup>	0.07	0.02	0.15 <sup>*</sup>
High Impact Articles	-0.17 <sup>***</sup>	-0.03	-0.15 <sup>*</sup>	-0.14 <sup>**</sup>	-0.12 <sup>*</sup>	-0.09 <sup>^</sup>
University Articles	-0.30 <sup>***</sup>	-0.32 <sup>***</sup>	-0.24 <sup>***</sup>	-0.26 <sup>***</sup>	-0.29 <sup>***</sup>	-0.24 <sup>***</sup>
University Patents	-0.04	-0.01	-0.04	0.01	-0.05	-0.03
<u>US Regions</u>						
Star Scientists & Engineers	0.04 <sup>^</sup>	0.08 <sup>**</sup>	0.19 <sup>***</sup>	0.07 <sup>**</sup>	0.11 <sup>***</sup>	0.19 <sup>***</sup>
High Impact Articles	-0.02	-0.04	-0.03	-0.03	-0.03	-0.04
University Articles	-0.07 <sup>**</sup>	-0.08 <sup>**</sup>	-0.09 <sup>**</sup>	-0.08 <sup>**</sup>	-0.04 <sup>^</sup>	-0.04 <sup>^</sup>
University Patents	-0.03	0.00	-0.02	-0.02	-0.03	-0.03

Notes: Significance levels: <sup>^</sup> 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.

Table 6. Star Scientists & Engineers Entry – *De Nova* or into New Science Areas – Poisson Regressions  
Top-25 Science & Technology Countries, 1981-2004

Explanatory Variables	Science and Technology Areas of Firm Entry					
	Bio/Chem/Med	Computing/IT	Nanotechnology	Semiconductors	Other Sciences	Other Engineering
Star Scientists & Engineers Active in Country in Same S&T Area as Entry	0.0044*** 0.0002	0.0244*** 0.0012	0.0847*** 0.0106	0.0259*** 0.0033	0.0321*** 0.0031	0.0594*** 0.0090
High Impact Articles Knowledge Stock in Same S&T Area as Entry	-0.0016*** 0.0003	-0.0073*** 0.0014	-0.0203 0.0170	-0.0072*** 0.0020	0.0024 0.0017	-0.0059 0.0036
University Articles Knowledge Stock in Same S&T Area as Entry	0.0000** 0.0000	0.0000 0.0000	0.0002 0.0002	0.0000 0.0000	-0.0002^ 0.0001	0.0001 0.0001
University Patents Knowledge Stock in Same S&T Area as Entry	-0.0006*** 0.0001	-0.0056** 0.0016	-0.0004 0.0014	-0.0197** 0.0066	-0.0042*** 0.0009	-0.0032** 0.0009
Total Employment in Country (millions of persons)	-0.0016*** 0.0004	0.0002 0.0004	0.0008 0.0006	0.0003 0.0003	0.0001 0.0005	-0.0006 0.0005
Constant	1.8574*** 0.0917	0.2329** 0.0872	-1.7455*** 0.1240	0.2903** 0.0845	-0.0285 0.1227	-0.6813*** 0.1094
Dummy = 1 in 2002, else 0	-1.9511*** 0.3415	-1.6336*** 0.4224	-1.2779** 0.4289	-2.0060** 0.6400	-1.8006*** 0.4168	-1.0710 0.7811
Dummy = 1 in 2003, else 0	-2.0719*** 0.3222	-1.7285** 0.5875	-1.8502** 0.6658	-2.8379*** 0.6696	-26.5872*** 0.3089	-34.8745*** 0.2250
Dummy = 1 in 2004, else 0	-3.4025*** 0.3039	-3.2753** 1.0006	-18.0601*** 2.8397	-3.5817*** 1.0043	-27.8858*** 0.2989	-23.6125*** 0.2525
Pseudo R <sup>2</sup>	0.8462	0.7807	0.4807	0.7517	0.7254	0.7171

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. Star Scientists & Engineers Entry – *De Nova* or into New Science Areas – Poisson Regressions  
19 OECD Members in the Top-25 Science & Technology Countries, 1981-2004

Explanatory Variables	Science and Technology Areas of Firm Entry					
	Bio/Chem/Med	Computing/IT	Nanotechnology	Semiconductors	Other Sciences	Other Engineering
Star Scientists & Engineers Active in Country in Same S&T Area as Entry	0.0029*** 0.0005	0.0196*** 0.0016	0.0569*** 0.0090	0.0153*** 0.0020	0.0234*** 0.0028	0.0421*** 0.0032
High Impact Articles Knowledge Stock in Same S&T Area as Entry	-0.0005 0.0004	-0.0066*** 0.0012	-0.0184 0.0134	-0.0051*** 0.0012	0.0025^ 0.0014	-0.0076*** 0.0018
University Articles Knowledge Stock in Same S&T Area as Entry	0.0000 0.0000	0.0000 0.0000	0.0002 0.0001	0.0000 0.0000	-0.0002* 0.0001	0.0001^ 0.0001
University Patents Knowledge Stock in Same S&T Area as Entry	-0.0002 0.0002	-0.0060*** 0.0014	-0.0002 0.0012	-0.0140*** 0.0039	-0.0033*** 0.0009	-0.0028*** 0.0004
Total Employment in Country (millions of persons)	0.0153** 0.0051	0.0129*** 0.0032	0.0178*** 0.0033	0.0283*** 0.0033	0.0165** 0.0061	0.0250*** 0.0041
Constant	1.9293*** 0.0909	0.1272 0.1089	-2.0697*** 0.1790	-0.0735 0.0906	-0.1201 0.1228	-1.0313*** 0.1336
Dummy = 1 in 2002, else 0	-1.9896*** 0.2691	-1.5455*** 0.3586	-1.1091** 0.3412	-1.9332*** 0.4374	-1.7983*** 0.4641	-1.0762^ 0.6502
Dummy = 1 in 2003, else 0	-2.0552*** 0.2574	-1.8238* 0.7134	-1.6957* 0.6541	-2.6903*** 0.6045	-22.8978*** 0.3808	-29.3650*** 0.3016
Dummy = 1 in 2004, else 0	-3.0107*** 0.2633	-22.7622*** 0.2746	-22.7535*** 2.3691	-3.5082*** 0.8408	-19.0606*** 0.3455	-25.2621*** 0.4395
Pseudo R <sup>2</sup>	0.8606	0.8087	0.5434	0.8006	0.7458	0.7539

Notes: Robust standard errors in parentheses below coefficient estimates. N = 456. 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. Star Scientists & Engineers Entry – *De Nova* or into New Science Areas – Poisson Regressions  
6 OECD Non-members in the Top-25 Science & Technology Countries, 1981-2004

Explanatory Variables	Science and Technology Areas of Firm Entry					
	Bio/Chem/Med	Computing/IT	Nanotechnology	Semiconductors	Other Sciences	Other Engineering
Star Scientists & Engineers Active in Country in Same S&T Area as Entry	0.1733*** 0.0087	0.1711*** 0.0382	1.3765*** 0.1358	0.3729*** 0.0342	0.8998*** 0.0962	0.8318*** 0.1928
High Impact Articles Knowledge Stock in Same S&T Area as Entry	-0.0379*** 0.0067	-0.0646 0.0431	-0.0604 0.0596	-0.0584*** 0.0164	0.0420^ 0.0227	-0.0089 0.1272
University Articles Knowledge Stock in Same S&T Area as Entry	0.0000^ 0.0000	0.0002 0.0002	-0.0005 0.0004	0.0000 0.0000	0.0002^ 0.0001	0.0004 0.0004
University Patents Knowledge Stock in Same S&T Area as Entry	-0.0148** 0.0054	-0.2713^ 0.1466	-0.0445 0.0524	-0.6816** 0.2461	-0.0709 0.0776	-0.1813* 0.0715
Total Employment in Country (millions of persons)	0.0012*** 0.0003	0.0015** 0.0005	0.0015 0.0009	0.0014*** 0.0004	-0.0014* 0.0005	0.0024 0.0015
Constant	-0.4687* 0.1818	-0.9673** 0.2829	-3.3831*** 0.4150	-0.9816*** 0.1577	-2.3751*** 0.2985	-2.6041*** 0.6131
Dummy = 1 in 2002, else 0	-1.1622 0.7735	-13.4502*** 0.5724	-14.8247*** 1.1882	-14.5352*** 0.5035	-15.5150*** 0.5260	-14.3748*** 0.6896
Dummy = 1 in 2003, else 0	-1.4573^ 0.8802	0.2190 1.0741	-14.6169*** 1.2385	-13.8536*** 0.5423	-15.4642*** 0.5441	-14.3332*** 0.6715
Dummy = 1 in 2004, else 0	-0.6850 0.7778	-0.2369 1.0359	-15.1510*** 1.1339	-14.4317*** 0.5174	-15.3493*** 0.5371	-14.4392*** 0.6471
Pseudo R <sup>2</sup>	0.3915	0.3049	0.4193	0.3154	0.3802	0.2326

Notes: Robust standard errors in parentheses below coefficient estimates. N = 144. 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 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 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 C,F 01 D,F 01 K,F 01 L,F 01 M,F 01 N,F 01 P,F 02 C,F 02 D,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 C,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