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Abstract

We examine the labor market for the highly trained in nanotechnology and the response of universities toward providing training. We draw comparisons with the labor market and university response in bioinformatics. The demand analysis is based on position announcements in *Science* in 2002 compared to 2005. We also analyze online position announcements in late 2005 and early 2006. Our analysis leads us to conclude that at the present time the market is small and growing for positions in academe and at FFRDC's, small and stable for positions at firms. Our analysis of training leads to the conclusion that the pipeline is being filled primarily through a principal investigator approach, where a student is attached to one faculty member's lab, rather than to a formal program. The fundamental difference between nanotechnology and bioinformatics in this respect may be due to differences in the opportunities available to universities and faculty.

Key words: nano-science; nanotechnology; labor market; bioinformatics; pipeline; faculty incentives.

JEL Classification: J24, 031, 032, 038.

Section I. Introduction

The public's enthusiasm for nanotechnology has often been accompanied by bold predictions regarding the labor market for jobs related to nanotechnology. It is fairly commonplace, for example, to cite the National Science Foundation's prediction that by 2015 nanotechnology will result in the creation of 2 million jobs worldwide.[1] The implication is not only that nanotechnology promises jobs but also that labor market bottlenecks, especially at the highly skilled end, could dampen the economic returns to investing in nanotechnology.

Yet universities, both public and private, have been rather slow to create new degree programs in nanotechnology. This stands in marked contrast to the response of universities in the late 1990s to a described "shortage" of individuals in bioinformatics when US universities created more than 74 new programs in the span of five to six years (Black and Stephan 2004).

This note examines the labor market for the highly trained in nanotechnology. Our research is focused primarily, but not exclusively, on the United States. Section II focuses on the demand for the highly educated in nanotechnology; Section III examines what we know about the pipeline of individuals being trained in nanotechnology. Conclusions are drawn in Section IV.

Section II. Position Announcements in Nanotechnology

We use two approaches to obtain information concerning demand. First, we examine job announcements listed in *Science* during the first ten months of 2005. We

[1] See, for example, the website for the National Nanotechnology Initiative: http://www.nano.gov/html/edu/home_edu.html.

choose *Science* because it serves as a consistent source of science-related job announcements and also because an existing dataset on job announcements in *Science* in 2002 (Stephan 2003) allows for a comparison between the two periods. One drawback to using *Science* is that its listings are likely biased towards positions in academe. Moreover, the minimum cost of $480 for a print announcement may discourage use.

To address these drawbacks and learn more about demand in other sectors of the economy, we use a second approach, drawing on job announcements listed on nine websites.[2] The websites were chosen because of the magnitude of their listings, their focus on nanotechnology-related jobs, their prominence in extensive internet searches for nanotechnology-related jobs, their mention on other websites and the recommendation of individuals working in industry and in nanotechnology education. While announcements from these sources are not exhaustive, we believe they serve as an indicator of demand in nanotechnology and are likely to capture a majority of openings announced on the internet, an increasingly common strategy for job recruitment.[3] Position announcements were selected based on the key words of "nano" or "mems" in the announcement. The choice of words came from talking with individuals working in industry. This method misses announcements that focus on fields related to nanotechnology but not included in these key words.[4] We collected data from December 12, 2005, to February 8, 2006.[5] In

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[2] The nine websites are: www.monster.com, www.careerbuilder.com, http://aaas.sciencecareers.org, www.nanoguys.com, http://naturejobs.nature.com, www.smalltimes.com, www.tinytechjobs.com, www.workingin-nanotechnology.com and www.memsnet.org.

[3] We believe the only way to enhance our understanding of demand would be to survey industry concerning hiring and faculty with regard to the placement of students.

[4] We recently searched on-line announcements using three additional terms suggested by Heinze (2004): "Quantumdot" did not turn up any ads on the websites examined: "Tunneling" turned up ads on two sites; most were related to computer networking, some to actual tunneling in the ground. The term "lithography" was associated with the largest number of announcements. The majority of these were engineering related in a broader sense than that used in nanotechnology, while some were art related. When we coupled

addition, we expanded the MEMSNET database to include a twenty-month period, beginning in February 2005 and ending in October 2006.[6]

Our benchmark data showed that during the first ten months of 2002, 32 position announcements were published in S*cience*, for a total of 41 positions.[7] Three-quarters of the positions are in universities; an eighth of the positions are at Federally Funded Research and Development Centers (FFRDCs) in the United States. Three (7.3% of positions) involve a government-university collaboration. Only two (4.9%) were placed by a firm. If a degree is mentioned, it is always a PhD.

When we perform the same search for the first ten months of 2005 we find that the number of position announcements more than doubled from 32 to 76 and that the number of positions has increased by three times, going from 41 to 120, an annual rate of 43%. When we extend the period to include November and December of 2005, we see a dramatic increase in the two-month period, for a year total of 171 positions in 100 announcements. Data for this twelve-month period are displayed in Tables 1 and 2. We do not know if the increase reflects a seasonal change in demand or a fundamental growth in positions. The largest number of positions were advertised at two FFRDCs.

"tunneling" with the term "nano" no ads were identified; when we coupled "lithography" with "nano" six announcements were identified. We also explored using the word "nems." The results suggest that few if any positions would be added to those identified using "nano" or "mems."

[5] At the suggestion of academic nanotechnology representatives, we supplemented this analysis to include position announcements in www.careers.avs.org over a six-week period in August-October 2006. Thirty-one positions were announced in ten ads during this period. Eight of the ten ads listed were placed by universities; none by firms. The high number of positions was skewed by a single large announcement concerning 22 positions through the Madame Curie Research Training Network in Europe.

[6] We are not able to extend the analysis for the other websites because most websites only post announcements over a several-week period. Memsnet is an exception.

[7] Given that in many instances more than one position was announced, we present the data by number of positions rather than by number of announcements. Position counts represent a lower bound because some announcements do not state the specific number of position openings but only indicate more than some specified number or unspecified descriptions of multiple openings. In such instances, the lower bound was recorded. Efforts were made not to count repeated advertisements for the same position.

As in 2002, the majority of positions advertised in 2005 were in academic institutions. But positions were less concentrated by sector, with academe representing only 59.6%. The percent at FFRDC and government sectors grew considerably. The degree most likely to be requested was the PhD, but while 92.7% of the positions stipulated a PhD in 2002, only 46.2% stipulated a PhD in 2005. A degree was not specified for 49.7% of the positions, up from 7.3% three years earlier.[8]

Data for the on-line ads are summarized in Tables 1 and 2 as well. A total of 111 unique announcements were posted during the seven-week period for 125 positions. Positions were most likely to be in firms, followed by universities as a distant second. There were ads for 12 positions in government/non-profit. The vast majority of positions were at established firms; only a quarter were at new firms. Moreover, only a small percent of the positions were at dedicated firms; a handful of these were at firms that focused exclusively on nano; more were at firms that focused on mems technology.

Unlike the case of *Science*, almost all of the on-line ads specified a degree requirement (Table 2). A quarter of the on-line positions stipulated a bachelors degree, compared to none in *Science*. Of the entities placing ads, firms were the most likely to stipulate a bachelor’s degree, suggesting that many firm hires were in non-research positions. But a quarter of the positions announced on-line at firms required a PhD.

Additional information concerning demand was gathered by monitoring the MEMSNET.ORG website for the twenty-month period ending in October 2006. A total of 93 ads mentioned the word “nano” or “MEMS,” related to 110 positions. These position announcements were also heavily focused on firms (59.1%); only 33.6% were

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[8] We are unable to ascertain the preferred field of degree.

for positions at a university. The mix of requested degrees is different than that for the seven-week on-line series, being more highly skewed towards advanced degrees.

A virtue of the MEMSNET data is that it allows us to track ads over time. Unlike what we observed in *Science*, however, the number of positions announced was virtually constant over time.

Our study leads to several conclusions. First, evidence is mixed concerning the degree to which the market is growing. If we rely on position announcements in *Science*, many of which are for academe or at FFRDC's, we find that the market grew at an annual rate of 43% during the three-year period that we analyzed. This is an impressive rate of growth, and considerably larger than the 11% rate of growth that we reported in earlier work for the period 2001-2002. But the growth rate also reflects the small size of the market. If we rely on position announcements on MEMSNET, the majority of which were placed by firms, we find no growth trend over the twenty-month period studied.

Second, the market, as noted above, appears to be small. To put the figure in context, there are approximately 125,160 PhDs in physics (including astronomy), chemistry, material science and electrical (including computer) engineering working in the United States today, based on the most recent (2001) data available (National Science Foundation 2003). The 171 positions announced in *Science* represent less than 0.1% of all individuals trained in these four disciplines, as do the 125 positions advertised in the on-line ads.

Third, it has become less common to explicitly require that the job applicant have a Ph.D. This could reflect a change or a tightening of the market; it could also reflect that the PhD degree is implicitly assumed, rather than explicitly requested.

Fourth, a degree of specialization exists: Announcements in *Science* are overwhelmingly for positions in academe and government/non-profit; those on-line, although not exclusively, are more likely to be placed by firms.

Finally, numerous companies are hiring highly-trained individuals with nano skills. But unlike the early days of biochemistry, the market is not exclusively focused on small firms. Instead, we find a number of top-20 R&D firms hiring in the area. For example, IBM, GE, Motorola and Intel all placed position announcements for nano-scientists. More importantly, only a small percent are dedicated firms.

Section III. The Pipeline of Individuals Trained in Nanoscience

We examine the supply of nano talent by enumerating new programs and courses in nanotechnology as well as by studying the labs of scientists working in nanocenters.

Graduate Programs. Until quite recently, there were only a handful of graduate programs in nanotechnology. In the US, for example, the first PhD. program was established at the University of Washington in 2000. It is designed as an "option" program, and established in conjunction with existing PhD programs. The State University of New York at Albany founded a college of nanotechnology early in this century and claimed to have awarded the first two PhD degrees in nanoscience in December 2004. Rice University created a professional masters of science in nanoscale physics and the University of Massachusetts Amherst announced in July of 2005 that it will offer a new PhD program in nanotechnology. Other institutions have recently announced plans for graduate programs. Johns Hopkins, for example, recently received funding from the Howard Hughes Medical Institute for an interdisciplinary graduate research training program in nanotechnology for biology and medicine. The University of Texas announced in February 2006 that it will offer a doctoral program in nanotechnology beginning fall 2006.

Course Offerings. We examine course offerings of a sample of universities to explore the extent to which courses with "nano" in the description or title have grown over the period 1996 to 2006. The results are presented in Figure 1. The twenty-six institutions are divided into three categories: (1) thirteen universities with National Nanotechnology Infrastructure Network (NNIN) facilities; [9] (2) ten institutions that have at least one nano center affiliated with the institution, four of which overlap with the thirteen NNIN institutions--we refer to these as "lab" institutions for reasons that will be apparent in the discussion that follows,[10] (3) seven institutions drawn randomly from the population of institutions that had created at least one training program in bioinformatics –we refer to these as "non-recognized" institutions.[11]

During the ten-year period, the number of courses offered per year at the thirteen NNIN institutions grew from 10 to 148, an annual rate of growth of approximately 35%. (Figure 1). The courses are overwhelming offered in engineering departments (82%). Although the average number of courses at "lab" institutions was slightly higher,[12] a similar rate of growth occurred at the two sets of institutions. Non-recognized institutions were considerably slower to introduce courses with nano in the prefix.

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[9] The thirteen institutions are: Cornell, Stanford, Georgia Institute of Technology, University of Washington, University of Michigan, University of Minnesota, Pennsylvania State University, University of California at Santa Barbara, University of Texas-Austin, University of New Mexico, Harvard, Howard University, and North Carolina State University. As of 2006 these institutions were listed as sites of the National Nanotechnology Infrastructure Network (NNIN).

[10] The ten institutions are: Cornell*, University of Washington*, University of California Santa Barbara*, Harvard*, Rice, University of California Los Angeles, Northwestern, MIT, RPI and the University of Wisconsin Madison. A * indicates an overlap with the NNIN institutions.

[11] The seven institutions are Boston University, George Mason, University of Southern California, Duke, Washington University St. Louis, University of California Santa Cruz, University of Nebraska Omaha.

[12] For the entire period the average number was 3.3 at NNIN institutions and 4.7 at the lab institutions.

Indeed, none of the seven offered courses prior to 2000. Since that time, there has been considerable growth although the average number of courses offered by the seven was less than half the average at either NNIN institutions or "lab" institutions in 2006. Clearly institutions that self-selected (and have been selected) into the NNIN or institutions known for their nano-centers have a more nano-intensive curriculum.

Aggregated across institutions, we find that 16.5% of the nano-related courses were in material sciences, 13% in engineering physics, 10.5% in mechanical engineering and 10.4% in electrical engineering. Another 20% of the courses were in other fields of engineering, while 5.0% were in chemistry and 4.9% in physics.[13] The courses at "lab" institutions were less likely to be in engineering than those at NNIN institutions.

Laboratory Experience. Another way to examine the supply of individuals being trained in nanoscience is to observe the extent to which nanoscience labs engage graduate students and postdocs in research. To this end, we have a file of laboratories affiliated with 21 nano centers at 14 academic institutions; courses for ten of these "lab" institutions were examined above. Among the 14 campuses, we identify 719 faculty having a nanocenter affiliation. Based on the criterion that the lab have an established web page, we identify 415 unique labs organized by one of these faculty members. The median number of technical staff in the laboratory (including the faculty member) is 11; the mean number is 13. A sizeable number of staff are graduate students and postdocs. To wit, we identify at least 2506 graduate students and 821 post docs working in one of the 415 labs. We also document 507 undergraduate students affiliated with these labs. Using whole counts we find that principal investigators (PIs) directing these laboratories

[13] Discipline assignments were made by examining the name of the department offering the course.

are more likely to hold an appointment in engineering departments (243), while 166 are affiliated with a department of chemistry. Another 73 are affiliated with a department of physics.

Hands-on laboratory experience is essential in training students in nano-activities. But what is significant is that, by and large, students working in these laboratories appear to be attached to a single advisor. This is in contrast to many training programs, where students do rotations in order to be exposed to different laboratory techniques. This structure is perhaps a reflection of the organizational structure of the laboratories. The overall impression one gets from gathering the laboratory data is that each nano-lab resembles a start-up company, with the PI as president. Many of these labs have administrative staff dedicated to running the laboratory, just as small companies have a managerial hierarchy. In this respect, these laboratories resemble the structure of laboratories that have evolved in the biomedical sciences in the United States. But the difference between these nano laboratories and those in the biomedical sciences is that labs in the biomedical sciences are generally attached to formal training programs and the students, at least those supported on National Institutes of Health training grants, have formal rotation requirements.

When one compares the magnitude of the number of students who work in these laboratories with what we have learned about course offerings and graduate programs, one must conclude that it is clearly in the laboratory that the majority of training is occurring in the nanosciences today. Course offerings exist in the “lab” schools, as can be seen in Figure 1, but the number of courses is small compared to the overall number of courses offered at these research-intensive institutions. Moreover, these institutions have been slow to develop formal degree programs. To the best of our knowledge, only three of the 14 "lab" institutions had or were in the process of offering PhD programs in nanotechnology at the time of this writing.[14] Several others were developing formal masters programs. The field, whether intentionally or not, in the early years has opted for a PI approach, where students are attached to a single advisor rather than to a formal program.

We can only speculate as to why the PI approach has dominated in nanoscience. Our speculation includes the fact that resources have been relatively forthcoming for research in the nanosciences from state, federal and non-profit organizations, leading institutions to focus on research and PIs to scramble to set up nano laboratories. Second, establishing a nanocenter is an effective means for a university to signal that it is doing frontier research. Furthermore, the establishment of a center, rather than an academic program, avoids the politics of creating academic programs across departments and colleges. The opportunity for financial gain clearly plays an important role. Nano-science, with its potential to become the next biotechnology, encourages an entrepreneurial attitude on the part of faculty. Their laboratories not only resemble small firms; their laboratories are developing the intellectual property that, if not the foundation of a spin-off, has the potential of bringing large returns to the PI. This gold-rush mentality could encourage a proprietary approach to students.

Section V. Conclusion

We conclude that a market exists for those with skills in nano-technology but it is relatively small at this time and most of the growth is centered at universities and

[14] The three are the University of Washington, State University of New York Albany and the University of Texas-Austin.

government laboratories. In terms of supply, there is evidence that at this time the pipeline is being filled primarily through a PI approach, with students attached to one faculty member's lab rather than to formal programs.

Here we speculate as to why graduate programs in the nanosciences have been somewhat slow to develop, particularly when compared to the rate at which they developed in bioinformatics.   We see several factors at play. First, programs in nanoscience span disciplines, which means that multiple entities in the university must work together to create a successful program. This is also the case in bioinformatics, although fewer departments are involved than in nanoscience. There is also the issue that engineers lack training in biology and physical sciences and students in the physical sciences and biology lack training in engineering. But a similar issue exists in bioinformatics with biologists lacking training in computer science and computer scientists lacking training in biology. The real difference between the two may be due to the fact that requirements for nano programs are often daunting from a student's perspective, since the coursework is usually of an "add on" nature, not a substitute for other, required courses. Moreover, concern has been expressed that the curriculum in a nano program is too general, depriving students of in-depth expertise. There is also the concern that the nano field is "too young" to develop into a stand-alone program (Vogel and Campbell 2002).

The incentive to create programs in nanoscience may also be less clear than in the case of bioinformatics. For example, while in bioinformatics there was considerable attention in the press concerning the high salaries earned by individuals in bioinformatics and the argument that the "seed corn was being eaten," we find little evidence that this has occurred in nanotechnology. Universities arguably have put their efforts into research in nanotechnology, rather than into establishing new programs. This is due in part to the amount of funding (approximately $4 billion from the U.S. government, alone) that became available for research in nanotechnology, not to mention funds that states have invested in creating nano research centers in their states.

The different trajectory being followed by nano-education in its early years compared to that of bioinformatics may also be due to fundamental differences in terms of faculty opportunities. In bioinformatics, faculty often left to take positions in large pharmaceutical companies. It was uncommon for faculty to remain on campus and start their own businesses; neither was it common for faculty with bioinformatic skills, especially those who came out of a computer science tradition, to have laboratories. In the nano sciences, faculty, to the extent that they are involved with industry, can do so and remain at the university. Their laboratories are developing the intellectual property that, if not the foundation of a spin-off, has the potential of bringing substantial returns to the PI through royalty payments. Such opportunities may contribute to a proprietary attitude towards students and provide the incentive to train students in individual labs rather than in a formal program.

Table 1
Positions Announced by Institution Type and Source

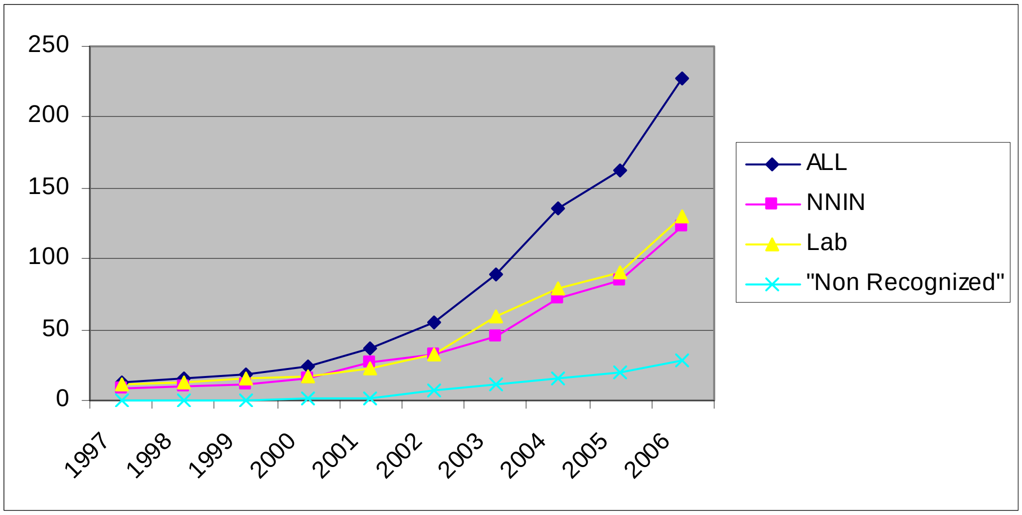
	Number	**Percent**
On-line	125	100
Firm	91	72.8
Established	55	Of firms: 60.4
New	23	Of firms: 25.3
Unknown	13	Of firms: 14.3
Dedicated	17	Of Known Firms: 21.8
Government/non- profit	12	9.6
Academe	22	17.6
Science	171	100
Firm	6	3.5
Established	6	Of firms: 100.0
New	0	Of firms: 0.0
Unknown	0	Of firms: 0.0
Dedicated	0	Of firms: 0.0
Government/non-profit	63	36.8
Academe	102	59.6

Note: Percent dedicated is based on number of new and established firms.

Table 2
Positions Announced by Degree Type and Source
(Percent)

Institution/Degree	**BA**	**PhD**	**Multiple**	**Not Specified**	**Total**
On-line Announcements	32 (25.6)	48 (38.4)	42 (33.6)	3 (2.4)	125 (100.0)
Firm	30 (33.0)	24 (26.4)	37 (40.7)	0 (0.0)	91 (100.0)
Government/non-profit	0 (0.0)	8 (66.7)	3 (25.0)	1 (8.3)	12 (100.0)
Academe	2 (9.1)	16 (72.7)	2 (9.1)	2 (9.1)	22 (100.0)
Science Announcements	0 (0.0)	79 (46.2)	7 (4.1)	85 (49.7)	171 (100.0)
Firm	0 (0.0)	3 (50.0)	1 (16.7)	2 (33.3)	6 (100.0)
Government/non-profit	0 (0.0)	6 (9.5)	1 (1.6)	56 (88.9)	63 (100.0)
Academe	0 (0.0)	70 (68.6)	5 (4.9)	27 (26.5)	102 (100.0)

Figure 1
Nano-related Courses by Type of Institution



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