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PERSPECTIVES

Nanotechnology between the lab and the shop floor: what are the effects on labor?

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Abstract Nanotechnology's effects on labor and employment have received little attention within research and debates on the social implications of nanotechnology. This article shows that, in spite of its incipient development, nanotechnology is unquestionably moving toward manufacturing, involving a still very small but increasing component of the labor force. Based on secondary data and the literature review, I compose a picture of the emerging jobs in nanotechnology and highlight four emerging trends in nanotechnology workers' skills requirements. I show that, in addition to job creation, nanotechnology diffusion is likely to pose labor market changes that may be disruptive for some categories of workers.

Keywords Nanotechnology · Labor · Employment · Social implications · International perspective

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Introduction

Over the last 10 years, nanotechnology has been persistently presented as a disruptive or revolutionary technology, with capability to deeply transform the economy and society at large. It has also been characterized as a general purpose technology, with a broad potential for application across the most varied sectors of the economy. In addition, in the context of the ongoing economic globalization and the spread of nanotechnology initiatives to more than 60 countries,[1] nanotechnology development has been regarded as a global endeavor. Such a revolutionary, general purpose and global-reaching technology suggests a wide-ranging process of industrial restructuring and, with it, significant changes in labor demand and global labor distribution. Given the convergence of sciences on which nanotechnology is based and the new techniques necessary to produce materials and devices at the nanoscale, it is also reasonable to expect significant changes in the labor force's skill profile.

Twenty-five years have passed since the time the first discoveries that paved the way for the development

[1] At least 60 countries have nanotechnology programs. (Sargent 2008, p. 10) In spite of their different magnitudes and accomplishments, these programs have in common a focus on developing nanotechnology R&D to increase their countries' industrial competitiveness in the global market.

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of nanotechnology.[2] Over the last decade, ever-increasing budgets were channeled to nanotechnology R&D worldwide. Companies started manufacturing and commercializing the first series of products enabled with nanotechnology. An academic and civil society discussion on the social and ethical implications and risks of nanotechnologies accompanied both the emergence of nanotechnology initiatives and the proliferation of nanotechnology products. However, nanotechnology implications for labor have been barely addressed so far, with the exception of the risks posed by nanoparticles in the workplace. In spite of the increasing attention given to nanotechnology education, the discussion has been centered on top R&D personnel, while issues related to the rank and file of the industrial workforce merited much less attention.[3] Attempts to analyze other dimensions of labor in the context of the emergence of nanotechnology—starting with the central questions of how the nature of labor and employment may be affected by these new technologies—are rare.

This situation contrasts sharply with the vivid debates on labor transformation, triggered by the emergence of previous technologies in the past. As Woirol (1996) notes, the debates can be traced back to classical economists, who discussed the topic in the context of the unemployment and abrupt disappearance of some trades during the first industrial revolution. Smith (1994/1776) and Say (2007/1803) sustained that technology makes goods cheaper, generating more demand, and then allowing the economy to reabsorb any technologically displaced labor—what was named the compensation theory. On the other hand, Ricardo (1996/1817) and Marx's (1990/1867) views were less optimistic. The former acknowledged detrimental effects of machinery on the working class, while the latter viewed progressive unemployment as a result of the ever-increasing fixed capital-to-labor ratio that characterizes capital accumulation. Successive technological breakthroughs, such as the emergence of the science-based industry in the early-twentieth century, and the post World War II advances on industrial automation, fed new debates, often polarized between the views of labor compensation and the idea of structural unemployment—a term coined in the 1960s. The most recent episode in this old debate was on the effects of microelectronics and information technologies. Labor compensation in the long run and unemployment generated by labor-saving technologies were again at the center of the discussion among economists (Freeman 1981; Soete and Dosi 1983; Freeman and Soete 1994). The high unemployment figures of the 1980s and the sharp reduction and even disappearance of the entire categories of jobs among postal workers, bank tellers, telephone operators and printers, introduced a more pessimistic tone (Noble 1995). The debate went on to the analysis of the significant transformations in the nature of labor in industries and services, such as more abstract, collective, and flexible work (Kern and Schuman 1989; Piore and Sabel 1984). The relocation of labor along global production chains, made possible in a scale without precedent by information technologies, and the parallel increase of high-tech skilled jobs and precarious and instable jobs put in evidence the complex nature of technology-driven labor changes in the so-called network society (STOA 2007; Baldoz et al. 2001; Castells 1996).

Why are labor issues attracting so little attention in the context of nanotechnology's early diffusion? One important factor is that labor itself—as an organized social group—has been poorly involved in the discussion on the social implications of nanotechnology, while other organized social groups, such as environmentalists and consumers, and their agendas,

[2] In 1981, Binning and Rohrer developed the scanning tunneling microscope, an instrument that enables one to obtain images of individual atoms. A more complex version of this tool was developed 5 years later, the atomic force microscope, which allows imaging, measuring, and manipulating matter at the nanoscale. Soon after, in 1986, using this powerful new tool, researchers at IBM for the first time moved xenon atoms precisely into a desired position while writing the logo of the company. Other important discoveries were new molecules with broad applications in several nanotechnology areas. In 1984, Smalley, Curl, and Kroto, from Rice University, discovered the fullerenes, a carbon molecule that is neither graphite nor diamond and can have several shapes, and in 1991 the Japanese physicist Ijima's research on carbon nanotubes generated unprecedented interest in this nanostructure. Also in the mid-eighties, Eric Drexler published his controversial *Engines of Creation*, in which he envisioned molecular machines and a radical view of nanotechnology.

[3] Current discussion on the need to perform changes in STEM education at the K-12 level to include nanotechnology concepts has a view on the future nanotechnology workforce development. To some extent, the same can be said about nanotechnology awareness through informal education. However, education discussion has been more "science-pushed" than being articulated with research on ongoing changes in the workplace due to the introduction of nanotechnology.

have gained much more visibility in the public arena.[4] From an academic perspective, the lack of interest in the issue, confirmed by the scarce literature available, seems to result from a perception that it is too early to analyze changes in labor, since nanotechnology is still in a premature stage of development.

In this article, I claim that, in spite of its incipient development, nanotechnology is starting to be adopted in several production processes, at different levels of the production chain. Consequently, a presently very small but increasing component of the labor force is involved with nanotechnology. Since labor is the most relevant factor for societal cohesion and wealth distribution, as well as a key resource for innovation, and knowing from previous historical experience that technological changes do have profound impacts on labor, it is not too early but the right time to start analyzing initial nanotechnology-related labor changes.

In the "Nanotechnology: still in the lab, but already entering the shop floor" section, I present a set of indicators with the purpose of showing that nanotechnology is unquestionably moving toward manufacturing. In the "Nanotechnology jobs" section, based on the fragmented data available today, I compose a picture of the emerging jobs in nanotechnology. In the "Skill profile of the emergent nanotechnology labor force" section, relying on existing research, I highlight four emerging trends in nanotechnology workers' skills requirements. In the "Unstable jobs" section, I point out some likely job instabilities and disruptions provoked by the diffusion of nanotechnology that may affect the labor force. The article concludes with some remarks.

Nanotechnology: still in the lab, but already entering the shop floor

Nanotechnology was launched at the beginning of the twenty-first century as a big technoscientific enterprise, nurtured by generous funding. In the US, more than US$12 billion has been invested since the beginning of the National Nanotechnology Initiative (NNI) in 2000 (Lok 2010, p. 18). Global funding for nanotechnology reached US$18.2 billion in 2008, almost doubling the US$9.6 billion invested 3 years before (PCAST 2010, p. 17).[5]

As in the case of other emerging technologies, public funding has been decisive for the initial development of nanotechnology. However, companies have increased their share of investments, mainly since 2004, indicating a transition from the publicly supported research to commercial R&D. Global corporate funding (including corporate R&D and venture capital investments) first exceeded government funding in 2007, and this trend continued in 2008. The competition for the promised $US2.5 trillion nanotechnology market by 2015[6] is reflected in the fierce funding competition among the US, the EU and Japan, and the addition of China as a new global player (PCAST 2010, pp. 19, 24).[7]

[4] Some important workers' organizations that have been involved in the discussion on risks of nanotechnology include the European Trade Union Confederation (ETUC); the International Union of Food, Agricultural, Hotel, Restaurant, Catering, Tobacco and Allied Workers' Association (IUF), which represents unions from 120 countries; the Australian Council of Trade Unions (ACTU); The United Steelworkers, in the US; and the Chemical Workers of São Paulo, Unified Workers' Central, Brazil. Other nanotechnology implications for labor such as employment or training have been much less or not at all addressed. Only a very recent ETUC resolution issued on December 1, 2010 manifests concern with changes in work processes and working conditions that could disrupt the working environment, require new skills, and create inequalities among the working class (ETUC 2010). Still, a researcher at the ETUC's research institute stated that European workers in general are little aware of the emergence of nanotechnology and its implications (personal interview with Aida Ponce, ETUI, January 11, 2010).

[5] Market consultant firms present some different data. According to Lux Research (2010) global investment from governments, corporations, and investors in 2009 was US$17.6 billion. The same report indicates that venture capitalists cut investments in 2009 by 43% relative to 2008, due to the economic recession. Cientifica's (2008) Nanotechnology Opportunity Report provides a higher figure of US$25 billion ininvestment, including venture capital.

[6] An earlier estimation expected a $US3.1 trillion market for nanotechnology products by 2015. Such a figure was comparable to the total US manufacturing output in 2007 and to the current global ICT market (Palmberg et al. 2009, p. 22). More recently, Lux Research, taking into account the impact of the economic recession, estimated that the market will top the $US2.5 trillion mark in 2015 (Holman 2009; Hwang and Bradley 2010).

[7] Although the US is still the country that invests most in nanotechnology, Asia, as a region, surpassed the US in 2008. In 2008, the US invested US$5.7 billion while Asia (primarily Japan, China, and South Korea) invested US$6.6 billion, US$4.7 billion of which was Japanese (PCAST 2010, p. 24).

As a result of the stimulus provided by public programs and private investments, nanotechnology research blossomed, a fact clearly reflected by a sharp increase of publications in the field (Youtie et al. 2008),[8] which are growing at rates superior to all publications in the US, the EU, and in several developing countries (Palmberg et al. 2009, pp. 35–36). Moreover, R&D outcomes are being patented fast. The number of non-overlapping nanotechnology patent applications increased annually by 34.5% from 2000 to 2008 (Dang et al. 2010, p. 689). Nanomaterials and nanoelectronics are the most patented nanoscale innovations, and the top 30 patent assignees are mostly the multinational corporations based in the US, Japan and Europe (Palmberg et al. 2009, pp. 55–56, 62).

Although many of the radical innovations promised by nanotechnology researchers and policy makers are barely announced in scientific publications or are still in the making in university and corporate labs, the first round of nanotechnology innovations—mostly based on passive nanostructures[9]—is already spreading throughout the industry and the market. The number of companies with activities in nanotechnology is rising, as is the commercialization of nanotechnology materials, as well as intermediate and final nanotechnology-enabled products.

Between 1990 and 2008, 17,600 companies from 87 countries[10] were involved in nanotechnology publications and patent applications (Roco et al. 2010b, p. 410). Even though involvement in publications or patents does not indicate the degree in which nanotechnology is being explored by these companies, this figure states that a large group of firms are either current or potential developers/users of this technology. Companies involved in nanotechnology comprise start-ups as well as many large corporations, both in high technology and more traditional industries (Baker and Aston 2005; Hullman 2006; Cientifica 2008; Youtie et al. 2009). Nanowerk's Nanotechnology Company Directory (Nanowerk 2010a) reports 2,146 companies from 48 countries involved in nanotechnology research, manufacturing, or applications. Half of these companies are in the US, 670 in Europe, 230 in Asia and 210 in other regions of the world. Helmut Kaiser Consultancy (2007) accounted 1600 companies around the world.

Nevertheless, as noted by Palmberg et al. (2009), the actual number of companies may be much greater than the ones suggested by international inventories. Inventories by country report considerably larger pools of firms. For instance, Small Times reported 1455 nanotechnology companies only in the US at the beginning of 2005 (cited by Palmberg et al. 2009). Germany had about 750 companies developing or marketing nanotechnological products or services in 2009 (BMBF 2009, p. 3). The Italian Trade Commission in Shangai (ITC 2009, p. 10) estimated that China had 700–900 companies active in nanotechnology in 2003. Israel claims to have 80 large and small companies in the nanotech sector (Halevi 2010). A study carried out by The New Energy and Industrial Technology Development Organization in Japan reported 586 companies in nanotechnology by 2005 (Nanotechnology Research Institute 2005). The 2nd Italian Nanotechnology Census identified 86 companies active in nanotechnology in Italy (ICE 2009). The number of companies with activities in nanotechnology is also increasing in developing countries. Brazil has 150 companies developing or using nanotechnology, including both start-ups and already established companies (Baibich 2010; Invernizzi 2009). There are 47 nanotechnology start-ups in Iran, plus some established companies adding nanotechnology to their activities (Sarkar 2010).

Some countries carried out surveys on nanotechnology activities. While not representative of the global activities, these surveys provide interesting

[8] In 2008, for the first time, the US lost its lead in nano-related publications, ranking second after the EU-27 region; by 2009, the EU was still leading, but China (including Taiwan) was the second, and the US was the third (PCAST 2010, p. 20).

[9] According to Davies (2008), at the moment, passive nanostructures— in which the nanomaterial or structure does not change its form or function—are predominant. These nanostructures are added to the already existing products and materials to enhance them, configuring incremental innovations. Active nanomaterials, which are able to change their form or function, will bring about major breakthroughs in the future. Roco (2010, p. xxxvii) considers that active nanostructures started being incorporated into products in 2005, and that these will undergo further development in the coming years. According to Subramanian et al. (2010), bibliometric analyses from 1995 to 2008 show that there is a sharp rise in active nanostructures publications from 2006 onward, suggesting a transition to this more complex phase of nanotechnology development.

[10] The authors note that 93.8% of these companies were located in 20 leading countries (Roco et al. 2010b, p. 410).

primary data on companies' characteristics, research and commercialization, synthesized in Table 1. With the exception of Japan, small and medium size firms are the most represented. While a group of companies is already actively commercializing products, most of them expect to increase their commercialization in 2–3 years time. A varied range of sectors are involved, but nanomaterials, nanobiotechnology and nanoelectronics are the most represented. In spite of the abundance of small companies—according to Lux Research (2006), they comprised about 80% of the companies with nanotechnology R&D plans in 2004—it is worth noticing that large companies concentrating on the largest shares of R&D, already monopolize patents in nanotechnology, and oligopolize several nanomaterials' production (Palmberg et al. 2009; Cientifica 2008).[11]

Accordingly, with the escalating number of companies worldwide, and their intensification of commercialization, the global nanotechnology market is increasing. The market of final products containing nanotechnology was US$224 billion in 2009, almost eight times the value achieved in 2005 (US$30 billion). The nanotechnology intermediates market was about US$29 billion in 2009 (PCAST 2010, p. 19). The US, Europe, and Asia have the bulk share of the nanotechnology market, with 36, 31, and 27% respectively. The rest of the world is responsible for only 6% of nanotechnology products sales (Roco et al. 2010b, p. 438). Although these figures are low when compared with the most optimistic market projections, it is a clear, increasing trend worth noting. Direct information coming from the companies consulted in the previously mentioned surveys, which expect more involvement in commercialization in the coming years, indicates the likely sustainability of this trend. However, as in the rest of the economy, the economic recession that initiated in 2008 may have an adverse effect. According to Hwang and Bradley (2010). the economic slowdown had a decelerating effect on nanotechnology, disturbing the whole value chain, from nanomaterials to final goods, although to varying degrees according to industry.

Among the commercialized products in 2009, the largest share (55%) was from the materials and manufacturing industry sector, including products such as automobiles, industrial equipment, and building and construction materials. These products made use of nanotechnology-based components such as coatings, composites, and electronic components. The electronics and information technology sector accounted for 32% of the market, including items such as mobile devices with displays, and antimicrobial coatings enhanced with nanotechnology. Some 12% of nanotechnology-based products were in the healthcare and life sciences sector, primarily from nano-enabled drug delivery systems. Finally, one percent of nanotechnology-based products came from the energy and environmental sector, including items such as nano-enabled filtration membranes or batteries (PCAST 2010, p. 19).

Some efforts have been made to track the number of nanotechnology enabled products available for commercialization. Although this is a useful indicator of the degree of advancement of the incorporation of nanotechnology into the manufacturing processes, it is the one very hard to obtain. Available inventories are not exhaustive and follow different criteria and purposes, but their common trait is that they all show a clear trend toward a rapid increase of nanotechnology-enabled products. The Woodrow Wilson Center Project on Emerging Nanotechnology (PEN) reported 1317 consumer products from 29 countries in 2010, compared to 54 products in 2005 when the inventory started. More than a half of them are health and fitness products, including cosmetics, clothing, personal care, sporting goods, sunscreens, and filtration devices. Following in frequency are home and garden, food and beverage, and automotive products (PEN, 2010). Helmut Kaiser Consultancy estimated that there were 2500 nanotechnology-based products and applications on the market worldwide, a sharp increase from the 300 identified in 2001. Currently, the US leads the nanomarket, followed by China, Japan, and Germany, but the report estimates that within 5–10 years China will be in the first position (Helmut Kaiser Consultancy 2010). The European Consumer Voice in Standardisation (ANEC) and the European Consumers' Organisation (BEUC) have produced The 2010 Nano Inventory, showing that the number of products containing nanomaterials has tripled, increasing from 151 to 475 products from 2009 to 2010 (Euroactiv 2010). The German Professional Association of Construction Industry

[11] The list of the top 30 patents assignees are long-established multinational enterprises based in the US, Japan, and Europe (Palmberg et al. 2009, p. 62).

Table 1 Size and activities of nanotechnology companies in several countries

Country	Survey	Date	Number of companies[1]	Companies' size	Nanotechnology activities
Australia	Nanotechnology Business Survey: Australia Dept. of Industry, Tourism and Resources/Nanotechnology Victoria.	2006	134	35% small firms (less 20 employees); 19% large firms (over 1000 employees)	• 49% involved in manufacturing, 33% developing nanotechnology products • Main knowledge areas of the firms: materials, chemicals and nanotechnology
Canada	Pilot Survey on Nanotechnology in Canada: Canada Statistics	2005	88	82% small firms, 8% medium and 10% large firms	• 91% active in R&D and 27% in the production/marketing stage • Greatest involvement in nanomaterials and nanobiotechnology.
Finland	Nano Survey Finland: Spinverse	2006	94	1/3 large firms, 1/3 small firms, and the remaining micro and medium sized	• Most of the firms estimate 2–4 years for their products to reach the market; some already commercializing • Main sectors of activity: electronics, chemical and materials
Germany	The German survey on the Economic Potential of Nanotechnology: VDI Technology Centre, HfB BSFM, and Nano and Micro Tech. Consulting.	2003	107	Majority of small and medium firms; 35% with less than 20 employees	• 66% manufacturers; 29% users of externally developed technology; 45% doing product development • 90% have plans to increase activities and employment • More represented sectors: chemicals and instruments
Italy	2nd Census of Italian Nanotechnology: AIRI/Nanotech IT	2006	86	32% large firms; 40% small and medium; 28% micro	• R&D efforts are concentrated in large well-established companies in technology intensive sectors
Japan	Study on Regional Activities Related to Nanotechnology: New Energy and Industrial Technology Development Organization	2004	586	80% large companies	• Companies already commercializing nanotechnology products are the larger ones, with a long tradition in business. • Most represented sectors of activity: materials, IT/electronics, measurement and ultrafine processing technologies.
The United States	2009 NCMS Study of Nanotechnology in the US Manufacturing Industry: National Center for Manufacturing Sciences	2009	270[b]	50% new business and spin offs with less than 10 staff 75% of the organizations have less than 20 employees.	• 2/3 of the respondent's organizations were directly involved in nanomanufacturing value chains • 25% already marketing products. By 2013, near 80% expect market ready products. • Dominant application markets: electronics, energy, pharmaceutical/biotechnology, aerospace, chemical, defense

Synthesis of surveys' findings

Source: Elaborated by the author mostly based on Palmberg et al. (2009); and also ITC (2009), NCMS (2010), Murayama (2006), and the Nanotechnology Research Institute (2005)

[a] The numbers in this column correspond to the companies that responded to the survey, not to the actual number of companies in each country, or to the number of companies to which the survey was sent. Note that the representativeness of the surveys varies greatly among countries

[b] The survey was targeted to senior executives rather than companies. There is no exact information on the number of companies reached by the survey

(BGBAU 2010) has recently issued a non-exhaustive list of 63 construction and cleaning products using nanoparticles.

According to Michael Holman from Lux Research (interviewed by Katz 2010), so far, the most nano-related developments have resulted in incremental improvements to products rather than the creation of revolutionary advances.[12] Roco et al. (2010a, p. xiii) agree with this perspective, stating that most nanotechnology products are based on relatively simple nanostructures. However, they emphasize that other products are sophisticated tools used for meeting the needs not addressed by current technologies (e.g., point-of-care molecular diagnostic tools, imaging agents, and even life-saving therapeutics). Moreover, there has been extensive penetration of nanotechnology into several critical industries: catalysis by nanostructured materials impacts 30–40% of the US oil and chemical industries; semiconductors with features under 100 nm constitute over 30% of that market worldwide and 60% of the US market; and molecular medicine is a growing field (Roco et al. 2010a, p. xviii).

The production of key nanomaterials is another important indicator of the dynamism of nanotechnology incorporation into manufacturing. Let us consider, for instance, carbon nanotubes, a key nanomaterial with applications in varied areas such as electronics, plastics, textiles, biomedicine, ceramics, and energy storage devices. A few years ago, carbon nanotubes were very difficult to produce and were traded in very low quantities. By 2004, there were 54 producers of nanotubes and nanofibers globally who, achieving massive improvements in capacity, produced 65 tons per year of these materials (Cientifica 2005). By 2007, research by the World Technology Evaluation Centre (WTEC 2007) reported a global capacity for the production of multi-walled carbon nanotubes of about 300 tons per year, and about 7 tons per year for the most complex single-walled carbon nanotubes. Foladori (2010)[13] identified 96 companies worldwide producing carbon nanotubes and fullerenes up to August 2010. Available data for only 13 of these companies of different productive capacities indicate a combined production of 2050 tons per year. In fact, nowadays, one state-of-the-art plant alone can produce as much as combined global production in 2007.[14]

The rapid increase in the number of companies and their production capacity shows, on the one hand, a dynamic market for these key nanomaterials, and therefore a growing incorporation of them into several intermediate and final products. On the other hand, as noted by Rejeski (2010, p. 38), the rapid increase in production capacity by companies is a signal that industry is gaining precision control over nanoscale processes. This, in turn, has effects on prices, decreasing the cost of nanomaterials, a condition for further diffusion. Just a few years ago, nanotubes were sold for over US$ 1,000 per gram. Although there is more demand than there is product available, increased productivity has dropped prices, and today single-walled nanotubes are available between 95 and 200 dollars per gram, and multi-walled nanotubes' price ranges from US$ 5–15 per gram, depending on their purity (Cheaptubes 2010). Other important nanomaterials are probably following the same trends as carbon nanotubes. Nanowerk's nanomaterial database reports 2624 different nanoparticles in use today, produced by 161 suppliers (Nanowerk 2010b).

The current value of nanotechnology market is far from the optimistic projection of US$ 2.5 trillion for 2015. Part of this can be attributed to the effects of the economic recession. Other obstacles, more intrinsically related to the nanotechnology development trajectory, have been pointed out as barriers for a more rapid commercialization. Among them are the high cost of several nanomaterials, process scalability

[12] After the initial excitement and very optimistic predictions about nanotechnology development, a more cautious approach is visible in policy and academic circles. A good example of it is the report on the evaluation of the European Framework 6 on Nanotechnologies and Nanosciences, Knowledge-based Multifunctional Materials and New Production Processes and Devices, the title of which, "Strategic Impact, not Revolution," clearly indicates that current European R&D is at an initial phase (Oxford Research and Austrian Institute for SME Research 2010, p. 168).

[13] Personal communication. Unpublished database.

[14] Bayer Material Science has recently opened a large carbon nanotube pilot facility in Leverkusen, Germany, boasting an annual capacity of 200 tons. The previous plant, started in 2007, had a capacity of 60 tons per year. Nanocyl installed a new reactor with a capacity of 400 tons per year of carbon nanotubes in Sambreville, Belgium, which will start operations this year. Another company, CNano, headquartered in California but with manufacturing in China, bought online a 500 ton per year facility for carbon nanotube production. (Nanotech Wire 2009; PlasticsToday 2010).

and quality control difficulties, scarcity of venture capital, fears of a public backlash, and regulatory uncertainty (ETC Group 2010, p. 8; Palmberg et al. 2009; Rejeski and Lekas 2008; McNeil et al. 2007, p. 10).

In spite of these obstacles, and the effects of the economic crisis, the aforementioned indicators reveal that nanotechnology is not only the science in the lab but has unquestionably started its diffusion into the industrial processes, along all the bonds of the production chains. Moreover, in the areas of materials and electronics—two sectors that are able to have broad repercussion in other sectors across industry—its presence is already important. Albeit nanotechnology is in an early stage of development, but as it enters companies' R&D facilities, production processes. and marketing strategies, it is starting to affect workers worldwide. How large is the nanotechnology labor market? What levels of the labor force are involved with nanotechnology? Are new skills necessary? Are some jobs at risk? I turn now to discuss these issues in the following sections.

Nanotechnology jobs

Soon after the NNI was launched in the US, it was estimated that that about 2 million nanotechnology jobs worldwide would be created by 2015, of which 800,000 will be in the US, 500,000 in Japan, 300,000 in Europe, about 200,000 in the Asia Pacific region (excepting Japan), and 200,000 in other regions of the world.[15] In addition, five million new jobs in related areas were expected (Roco 2003a).[16] A rather convergent projection for the US was made by the US Department of Labor (USDL 2006), which estimated that 671,000 nanotechnology jobs would be available from 2006 to 2016 in the US alone. The business consultancy firm, Lux Research, forecasted a larger nanotechnology labor market, with 10 million manufacturing jobs in nanotechnology by 2014, or 11% of jobs in manufacturing worldwide (Lux Research 2004).[17] A recently updated projection estimates that nanotechnology will require about six million direct jobs worldwide by 2020 (Roco 2010).

There are few labor market figures besides these estimations. Up to now, there is no statistical data regarding the actual number of workers involved in nanotechnology, not even job titles or job classifications that allow the identification of such workers. The very nature of nanotechnology, which is not a new industry, but a general purpose technology to be used in several industries, makes it difficult to define and identify nanotechnology workers. Attempts to assess the current number of nanotechnology jobs are scarce, and mostly restricted to companies exclusively dedicated to nanotechnology. It is much more complicated to assess which jobs can be considered under nanotechnology jobs category in companies that are becoming users of nanotechnology in traditional industries, or in companies that do not identify their activities as nanotechnology. Some efforts to measure nanotechnology jobs have been made in the US and Germany. In the US, Small Times estimated that 24,388 people were employed in nanotechnology companies in 2004 (NIOSH 2010). Lux Research (2007) reported 5,300 nanotechnology R&D employees by the end of 2006, and expected an increase up to 30,000 by 2008. More vaguely, the consulting firm estimated the existence of tens of thousands of blue collar jobs in manufacturing involving nanotechnology. According to Roco (2010) employment in nanotechnology has increased 25% per year between 2000 and 2008 and the current number of jobs in the US, including researchers and workers, is around 160,000.[18] In Germany, Luther and Malanowski (2004, cited in Schuman 2009)[19] estimated that companies in nanotechnology provided some 50,000 direct and 114,000 indirect jobs. A study based on a data stock of 860 German nanotechnology companies registered 63,000 direct jobs in 2008 and projected

[15] For comparison, two million is the number of workers in the IT sector across Europe (STOA 2007, p. 9).

[16] This estimate was based on the analysis of the existing nanotechnology R&D activities in industry in the US, Japan, and the Western Europe. The indirect jobs estimate was extrapolated from previous experience in the information technology sector (Roco 2003a, b, p. 182).

[17] This number of jobs was correlated to an estimation of a $US3 billion market by 2014 for nanotechnology products. This figure, however, was later reduced to US$2.4 billion by Lux Research (Holman 2009; Hwang and Bradley 2010).

[18] Personal interview, December 1, 2010.

[19] Original in German: Luther, W.; Malanowski, N. (2004): Nanotechnologie als wirtschaftlicher Wachstumsmarkt. Innovations- und Technikanalyse. VDI Technologiezentrum, Düsseldor.

that small and medium enterprises (SMEs) would need 43,200 new employees by 2013 (BMBF 2009). These data, enriched by some detailed research on nanotechnology job postings (Stephan et al. 2007; Freeman and Shukla 2008),[20] show that nanotechnology labor market is still small, but already exists.

In spite of the presumably small size of the current nanotechnology market, some studies reveal that companies are concerned with the possibility of a shortage of skilled nanotechnology personnel. In a survey involving 26 US companies, Lux Research (2007) reported that 60% of them consider that they will face a shortage of "nanotech talent."[21] The report Barriers to Nanotechnology Commercialization prepared for the Department of Commerce (McNeil et al. 2007, p. 31) indicates that the US relies on foreign skilled workers for this field and that there can be a shortage given the increased rate of return by foreign students to their home countries. The report is, however, more concerned with labor shortages at the technical skill level of recent graduates.

In the European Union, the fears of labor force scarcity seem to be more intense. In 2004, 44% of 733 respondents to the Open Consultation on the European Strategy for Nanotechnology expected a shortage of trained staff in nanotechnology within 5 years, and another 24% in five to 10 years. The respondents claimed the lack of highly skilled staff to be the main difficulty for SMEs and start-ups in nanotechnology (Malsh 2008, p. 3). The nanotechnology skills and training survey conducted in the UK (Sing 2007, p. 22) showed that half of the research institutions, companies and training institutions reported problems regarding the availability of human resources, which were more severe in the case of technicians. The Spinverse (2006) survey in Finland found that 44% of the surveyed 93 companies pointed out that the recruiting of skilled people had been "difficult" or "very difficult." About one-third of the 107 companies surveyed by VDI Technology Centre in Germany in 2003 pointed out the lack of skilled personnel as one possible barrier for the development of nanotechnology (Palmberg et al. 2009, pp. 86, 92; Luther 2007, p. 30).

A few available studies, carried out in Germany, the US and England provide information on personnel allocation among different nanotechnology activities within companies. These studies converge in pointing out a moment of transition in which nanotechnology labor demands not only come from the R&D labs but are encompassing a broader spectrum of nanotechnology activities along the production process and related activities. These findings are therefore coherent with the figure portrayed in the first section regarding the increasing use of nanotechnology in production.

Some pioneer research has been done in Germany to analyze the activities and skills involved in nanotechnology jobs. Henn (2004, cited by STOA 2007)[22] surveyed 42 nanotechnology companies and found that, irrespective of their size, they projected an equally strong demand for natural scientists, engineers and intermediate qualified workers for 2007. On the other hand, semi-skilled and unskilled workers were little needed. Based on secondary sources and previous research involving 151 employees from 132 establishments, Abicht et al. (2006, p. 38) showed that new demands in nanotechnology are beginning to emerge, involving, in addition to R&D, manufacturing, quality assurance, documentation,

[20] In the absence of more aggregate data, some researchers have analyzed nanotechnology job offerings to provide some data on the demand for a nanotechnology labor force. Stephan et al. (2007) analyzed job postings on nine websites over 20 months in 2005–2006 (125 positions), and announcements in Science during 2005 (171 positions). They concluded that while announcements for the academy in Science grew significantly in 2005 compared with a previous study made in 2002, the number of positions placed by firms in specialized websites remained stable over the analyzed period. Industry demands involved firms of different sizes and came mostly from non-nanotech dedicated firms. Another study conducted by Freeman and Shukla (2008) analyzed 5,370 job postings from SimplyHired.com over 12 months from March 2007 to March 2008. In addition, they contacted 80 companies offering jobs. The authors concluded that job growth in nanotechnology was modest and that companies are not having problems filling positions.

[21] In the US, concerns about a possible scarcity of skilled workforce are also present in nanotechnology documents, and have to be contextualized in a broader and older discussion on the decline of the immigrant qualified workforce the US has relied on. The Report to the President and Congress on the Third Assessment of the NNI recommends some strong measures to retain scientific and engineering foreign talents trained in the US (PCAST 2010, p. 30).

[22] Original in German. Henn, S. Gründungen in der Nanotechnologie. Clusterentwicklung und Förderung. ISW workshop "Nanobiotechnologie Entwicklungstendenzen und Qualifikationsanforderungen,' Berlin, April 15, 2004.

marketing and distribution. Another German study found that half of the labor force in 178 nanotechnology companies had university degrees, signaling the R&D intensive character of nanotechnology. About 10% were master craftsmen and technicians, and other 20% skilled workers. The later categories were expected to rise, according to the companies' projections (Aibithch 2009, p. 72).

In the UK, The Sector Skills Council for Science, Engineering and Manufacturing Technologies made an assessment of the skills required for advanced manufacturing (SEMPTA 2009, p. 56). The findings indicate that nanotechnology's industrial potential is still to fully emerge and that current skills requirements are focused on R&D, together with an understanding of intellectual property and new product development. Yet, as the manufacture of nanomaterials is increasing, highly skilled technicians and operators, capable of running complex equipment, are also in demand. Similarly, in the UK, a survey conducted by Sing (2007, p. 22) reported that nanotechnology hiring is dominant—both in industry and research institutions—in graduates and post-graduates for science research and product development, but demand is increasing for trained technicians.

In the US, the Department of Labor (2006) described employment opportunities in nanotechnology embedded within several occupations. Some of the most demanded positions require longer university training, such as positions for industrial engineers, chemists and sales engineers. Other in-demand occupations were projected for 2-year-university-trained personnel such as sales representatives, manufacturing, and technicians with different specialties. A more recent assessment by the USDL Occupational Information Network (ONET 2010) suggests the emergence of new nanotechnology occupations unique to nanotechnology such as Nanotechnology Engineering Technicians and Technologists and Nanosystems Engineers, as well as a continued demand for nanotechnology skills within the context of other occupations.

Additional information comes from research at the company level. A 2005 study based on interviews with 240 nanotechnology and microtechnology companies in the Bay Area Region showed that, in addition to needs for scientists and engineers, the companies' needs for technicians and manufacturing workers were increasing. The companies' hiring plans for the next 12 months included an increase of 32% for technicians, 22% for scientists and engineers, and 7% for manufacturing workers (Godbe Research 2006). A Lux Research (2007) survey of 27 companies indicated that companies will reduce the proportion of scientists in their labor force, and increase the share of engineers, sales, and marketing personnel in future hires, accompanying the development of nanotechnology manufacturing. Van Horn and Fichtner (2008, p. 12) conducted a survey that interviewed more than 50 individuals working for companies and research facilities in nanotechnology in Phoenix and Tucson, Arizona. Most companies stated that they will increase their use of the nanotechnology workforce in the future, although they did not make precise anticipations. Half of the respondents affirmed that the use of nanotechnology will change the skills of workers to a moderate or great extent in the next 3 years. In another study, Van Horn et al. (2009) examined two large pharmaceutical companies. Although the number of jobs affected by nanotechnology in these firms was small, the introduction of nanotechnology demanded changes in the skills of several positions, including R&D, manufacturing workers, corporate executives, marketing personnel and legal staff.

Taken together, these studies suggest that most of the labor force currently employed in nanotechnology is composed of highly educated scientists and engineers for R&D activities, which is consistent with the early development of this technology. However, there is also evidence that, along with the increasing manufacturing and commercialization of nanotechnology-enabled products, a demand for intermediately skilled positions is emerging, particularly for technicians and other categories of skilled workers.

Skill profile of the emergent nanotechnology labor force

What knowledge is necessary to work in nanotechnology and how is the labor force trained? In spite of the frequent mention of the need for a qualified nanotechnology workforce in early nanotechnology policy documents,[23] there is little field research so far

[23] The US National Nanotechnology Initiative states: "Workforce Education and Training efforts will promote a new generation of skilled workers with the multidisciplinary

about the emerging skills that are necessary to work in nanotechnology at different positions within companies, and along the production chains. Based on the existing literature, four trends were identified: (a) nanotechnology skills are based on an interdisciplinary science base; (b) nano-specific transversal skills are emerging; (c) the so-called soft skills are valuable; and (d) adaptive training prevails.

Nanotechnology skills are developed on an interdisciplinary science base

Nanotechnology is a galvanizing area that brings together several sciences and technologies. Interdisciplinarity is thus a key requirement in the field, regardless of the specific area of nanotechnology application. Fonash, who started one of the first workforce training programs in the US,[24] considers interdisciplinarity a condition of all nanotechnology workforce development, not restricted to R&D activities:

> The implication of the ever-widening impact of nanotechnology is that the workforce must have a broad background encompassing an understanding of the principles of biology, physics, and chemistry as well as encompassing the engineering principles of design, process control, and yield. The sciences provide the basic concepts behind nanofabrication and they dictate the rules of the nanoscale world. Biology, for example, is needed for two reasons: manufacturing will increasingly mimic biological systems assembly ("bottom-up" nanofabrication) and manufacturing will increasingly be fabricating systems for biomedical applications. Physics is needed because the nanoscale is the world of probability wave functions, quantum mechanical tunneling, and atomic force probes. Chemistry is critical because it provides the tools for tailoring molecules, functionalizing surfaces and "hooking" everything together. Of course, engineering principles are needed to ensure manufacturability and economic viability (Fonash 2001, p. 80).

In the same vein, the German skills research study concludes that nanotechnology requires general interdisciplinary cross-sectoral knowledge in natural sciences and in engineering, while specific skills require knowledge of different technical branches and natural scientific fields such as physics and chemistry, and their special branches, e.g., photonics, precision optics, laser technology or electroplating (Abicht et al. 2006, p. 38). Companies, research institutions and other stakeholders consulted in Europe and US surveys agree with the key importance attributed to interdisciplinarity (Malsh and Oud 2004; Godbe Research 2006; Sing 2007; Van Horn and Fitchner 2008; SEMPTA 2009).

However, there is no consensus at this point about the need for dedicated nanotechnology training as the preferred way to arrange such an interdisciplinary knowledge base. Findings of the Nanotechnology Skills and Training Survey in the UK (Sing 2007, p. 23) show that employers do not have a clear preference between a labor force trained as generalists in nanotechnology or as specialists in a particular scientific area. While 57% of employers indicated that both skills sets were valued, 24% said generalists were valued more than specialists. The 26 companies surveyed by Lux Research (2007) were evenly split as to whether nanotechnology degree programs are an advantage or detraction. McNeil et al. (2007, pp. 30–31), based on roundtables, focus group discussions, and interviews with the US businessmen, researchers, and public officials, concluded that there is not much need for a workforce trained specifically for nanotechnology in the near future, according to the present experience of large companies.

Interdisciplinarity has long-term implications for labor force training. There is an increasing agreement

Footnote 23 continued
perspectives necessary for rapid progress in nanotechnology" (NSTC 2000, p. 15). The European Commission Strategy for Nanotechnology maintains that "To realise the potential of nanotechnology, the EU needs a population of interdisciplinary researchers and engineers who can generate knowledge and ensure that this is, in turn, transferred to industry." And later on "Nanotechnology is a dynamic field that requires continuous training to follow the latest developments. As nanotechnology moves closer to the market, the need for training to assist in startup/spin-off creation, the management of IPR portfolios, safety and working conditions (including health and safety at work) and other complementary skills are important to ensure that innovators are better placed to secure funding and take forward their initiatives." (European Commission 2004, pp. 13–15).

[24] See Center for Nanotechnology Education and Utilization. Pennsylvania State University http://www.cneu.psu.edu/default.htm.

on the need to construct interdisciplinarity along the education system, from K-12, to have a well-qualified labor force in the future (Fonash 2001; Roco 2003b; Feather and Cockerill 2005; Healy 2009). As stated by Foley and Hersam (2006, p. 481): "a new educational paradigm should be implemented in which curricula are interdisciplinary from the beginning, thus introducing students to the connections between disciplines at the most fundamental levels and their relevance to the latest technological developments. An emphasis should also be placed on nurturing students' ability for lifelong independent learning."

Nano-specific transversal skills are emerging

Available research takes note of activities that demand nanotechnology-specific knowledge and skills, and therefore require dedicated training. These skills are of particular importance since they are transversal to all the fields of nanotechnology application. They are focused on three areas: characterization and analysis tools, fabrication processes and synthesis methods, and techniques regarding working conditions.

Nanotechnology R&D, manufacturing, and quality control require mastering some characterization and analysis tools, which are decisive to determine the atomic structure of materials. These new instruments are increasingly complex and automated. Companies surveyed underscored tools such as scanning electron microscopes, atomic force microscopes, scanning tunneling microscopes, transmission electron microscopes, and x-rays (Sing 2007, pp. 28–29; Abicht et al. 2006, p. 18; Van Horn et al. 2009, p. 58; SEMPTA 2009).

Another set of skills is related to fabrication processes and synthesis methods required by both R&D and manufacturing. Knowledge on the fabrication of nanostructures, nanoscale, and near-nanoscale devices, and synthesis of nano-scaled materials is required, including both top-down fabrication and bottom-up synthesis techniques. According to Sing′s survey, companies and research institutions considered most valuable knowledge of sol–gel technique, followed by lithography techniques, knowledge of self-assembly, and layer-by-layer techniques.

Finally, nanotechnology R&D and production sometimes require special working conditions such as clean rooms, and, in general, involve new materials and substances that require Environment, Health, and Safety (EHS) knowledge and practices, such as special protective clothing, material handling methods, product cycle, environmental care, etc. (Abicht et al. 2006, pp. 18, 58; Van Horn et al. 2009; SEMPTA 2009, p. 56; Trybula et al. 2009, p. 4).

At this moment, it is unclear if these new skills will be transformed into new, well-defined nanotechnology specific occupations, or if they will be necessary, in diverse levels of depth, for the entire core nanotechnology workforce.

"Soft skills" are valuable

When consulted on the desirable profile of a nanotechnology workforce, companies highlighted the importance of communicative/interpersonal skills, team working, creativity, ability to analyze, problem-solving capacity, leadership, and capability to learn (Malsh and Oud 2004, p. 60; Abicht et al. 2006, p. 39; Lux Research 2007; McNeil et al. 2007, p. 31). These skills are a mixture of competencies of personality and accumulated personal and collective labor experience. They are often referred to as soft skills.

Nanotechnology seems to reinforce the trend that accompanied the development of flexible production systems. In a context of tough global competition, accelerated innovation and increased and more complex automation, personality competencies, and the ability to transform knowledge into concrete actions in a collective work environment proved to be instrumental in coping with production challenges. The current context, in which companies are introducing a new technology, increasing the recurrence of production events (Zarifian 1995),[25] reinforces the value of such competencies. Moreover, team work and communication are abilities very strongly related to the interdisciplinary nature of nanotechnology.

[25] According to Zarifian (1995), flexible production environments pose challenges to workers labor situations characterized by events, some of them unexpected, and others provoked by accelerated process and product innovations. Work in such context means mobilizing knowledge and problem-solving competencies to address events.

Adaptive training prevails

At the current stage of nanotechnology development, the majority of jobs come from nanotechnology's penetration into classical industries to upgrade products and processes, while more significant innovations are gaining terrain in some sectors. New skills requirements are becoming evident, but are still not fixed, and incremental approaches to training are the most commonly used.

Sing's findings from the UK Skills Survey suggest that the training environment is still highly unstructured. Fifty-three percent of respondents indicated they do not have a training program for graduates and post-graduates joining their organization. Among the 32% of the respondents that did have a training program, a mix of methods was in use. The majority indicated on the job-training, followed by continual professional development programs and one week short courses (Sing 2007, p. 24). Similarly, in German companies, the required knowledge and skill components were mainly offered in the form of additional qualifications, building on the basis of existing qualifications in the fields of physics, chemistry, or biology (Abicht et al. 2006, p. 48). Another study (2009) confirms that most of the 178 German companies with activities in nanotechnology surveyed were doing in-house training (89%) and qualification on the job (88%). In the US, Lux Research (2007) interestingly notes that companies need both people with previous experience that can be trained in nanotechnology internally, and fresh labor force trained in the latest advances at the universities. Companies and researchers surveyed by Van Horn and Fichtner (2008, pp. 12–13) in Arizona claimed that advanced degrees in traditional disciplines provided much of the general knowledge and many of the skills necessary to learn the basics of nanotechnology research on the job.

Evidence shows that current nanotechnology skills are being constructed mostly on the job and updated by short courses. However, previous solid scientific training and job experience seem to be a crucial base requirement for such training. This applies for the R&D personnel as well as for the technicians and other skilled workers. In this process, companies are constructing valuable tacit nanotechnology knowledge. Considering the strategic value of tacit knowledge in technologically complex processes and in immature fields of production, and taking into account nanotechnology's broad areas of applications, it is very plausible that even when more formalized training systems emerge, on the job training will continue to be essential to nanotechnology skills development.

Unstable jobs

Nanotechnology development and its progressive adoption by companies not only create new occupations but also demand new skills. As part of the same process, adverse effects on some current occupations and skills are very likely to emerge, generating instability and changes in the labor market. These changes may be socially disruptive.

As nanotechnology provides companies with a new source for innovation, its adoption will create a new competitive environment. Companies' previous technological expertise and competitive advantages will be eroded. As Soete and Dosi (1983, p. 17) remarked in their analysis of emerging microelectronics, "the switch from an old technological paradigm to a new one [opens] dramatic new possibilities of change in the international structure of supply, the relative position between countries and the pattern of international competitiveness." Similarly, Lux Research's 2004 Nanotech Report warned that "nanotech is poised to ripple through the economics and value chain of multiple industries, with every new corporate opportunity also representing a potential threat… Just as the British industrial revolution knocked hand spinners and hand weavers out of business, nanotechnology will disrupt a slew of multi billion dollar companies and industries" (cited by Miller 2008, p. 216). Innovative companies, the front runners in the development and adoption of nanotechnology, will gain market advantages at the national and global levels, while less innovative companies may fail, generating changes in the industrial structure that will directly affect the labor market. Although this process of companies' rearrangement in a new competitive scenario is still in a very early stage, some of its features and emerging implications for labor can be anticipated.

New products and product substitution

New products resulting from technological change generally create new jobs, by stimulating a new demand. This is a usual "compensation theory" argument, and an empirically observable fact in many new products that appeared throughout the last century such as cars, vaccines, computers and cell phones, generating a previously non-existent demand. However, the same is not necessary valid for product substitution, that is, when an already existent product is substituted by a new, more efficient version of it, as a result of the application of a new technology. In this case, the likely outcome, depending on relative prices, is a partial or total shift in demand toward the updated product. For instance, demand can change from current pants to nanotechnology-enhanced anti-wrinkle, stain-resistant pants, or from current paints to nanotech scratch resistant paints. The great majority of the currently commercialized nanotechnology products fit better into this latter movement: they are not completely new products, but products that exhibit improved properties and functions when compared with traditional ones (Invernizzi 2009; Invernizzi and Foladori 2010). In the short term, considering the still incremental nature of nanotechnology innovation, job instabilities resulting from the decreasing competitiveness of firms that fail to adopt nanotechnology seem much more likely than job creation by the advent of completely new products.

There are further implications for employment related to this demand shift. First, since innovative companies are usually more productive than less innovative firms, sectoral rearrangements would likely result in a reduction in the overall sectoral employment, in conditions of equal total demand of products. Second, for countries with weak nanotechnology capabilities, there is a high risk of having imported nanotechnology-enhanced goods substituting local production and jobs. Third, as noted in a previous work (Invernizzi and Foladori 2010), nanotechnology-enhanced products often last longer (e.g., tires with increased resistance to abrasion), or require less applications (e.g., more efficient paints), or can be used more times (e.g., recyclable nanoclay filters for industrial effluents), or help other products or machines to last longer (e.g., anticorrosive coatings). These product's characteristics—as contradictory as they sound for marketing purposes—may have as a result a decrease in their own demand, therefore negatively affecting jobs.

Labor-saving processes and products

Process innovations have usually the most negative effects on employment since new technologies are applied to increase production efficiency and automation, requiring less labor force at a given level of production. At the moment, nanotechnology production techniques are struggling with scaling-up difficulties. However, it is possible to expect that two areas in which nanotechnology innovation is strong—computers and sensors— will contribute to the advancement of existing levels of automation in many industries (Pinto 2010; Brugger 2009).[26]

Much more visible at this moment are labor-saving product innovations, that is, products that incorporate some functions previously performed by workers. One example of this is the lab-on-a-chip, a diagnosis kit that will soon be available not only in hospitals but also on drugstores' shelves. Labs-on-a chip provide more rapid and secure results than conventional laboratory test, requiring much less qualified personnel, or even unskilled personnel (Smarter Technology 2009).[27] Food and beverages packages enhanced with nanotechnology have sensors that

[26] Recently, some Duke University engineers have adapted a decade-old computer-aided design and manufacturing process to reproduce nanosize structures with features on the order of single molecules. They used the traditional computing language of macroscale milling machines to guide an atomic force microscope. The system reliably produced 3D, nanometer-scale silicon-oxide nanostructures through a process called anodization nanolithography (Morgan 2007). This suggests that, at least in the short run and in some production techniques, nanotechnology process innovation may upgrade the existing automation infrastructure rather than contribute a radically new process.

[27] Based on its expertise in silicon chip fabrication, surface chemistry, and nanotechnology, IBM Research has developed a lab-on-a-chip technology that can perform instant point-of-care tests for avian flu, swine flu, breast cancer, prostate cancer, bacterial infections, poison, and toxins. Within 2 years from now, IBM claims its lab-on-a-chip technology could become as commonplace as off-the-shelf pregnancy tests, allowing anyone to perform instant, inexpensive tests for medical conditions that today take skilled personnel hours to perform. The IBM lab-on-a-chip test returns "yes" or "no" results from a pin prick of blood in just a few minutes (Johnson 2009).

indicate conservation conditions by visible signs like changing colors. They can also generate automatic delivery of food preservatives, increasing the shelf life of products, and reducing waste (Garber 2006; Lyons 2006). Because these products can remain longer in storage and on supermarket shelves, activities involving the transport of goods, taking stock, checking on the state of products, maintaining the products, and running sales will likely be reduced. Other nanotechnology innovations such as self-cleaning glass, anti-wrinkle and anti-odor clothes, anti-bacterial hospital materials, anti-scratch and self-repairing paintings, protective coatings for industrial machines, etc., tend to reduce the need for maintenance and repair jobs (Invernizzi and Foladori 2010).

Substitution of natural raw materials with new nanotechnology-based materials

As nanotechnology innovations are strongly focused on materials, the substitution of natural raw materials with new nanotechnology-based materials constitutes a central issue in the analysis of nanotechnology implications for labor. The ETC Group has called attention to this matter and the risks of significant labor displacements since the beginning of the last decade (ETC Group 2003). Later on, in a report for the South Centre (2005) and another for the UN Non-Governmental Liaison Service (ETC Group 2008), ETC alerted that a significant number of occupations could be at risk in a great number of developing countries that are heavily dependent upon commodities. Based on case studies on rubber, textiles, platinum, and copper, the reports provide examples of how economies and workers in the global South could be affected by nanotechnology development. Yet, it was noted that, at least for some countries, there is also an opportunity to add value to current commodities with nanotechnology. A study by the Meridian Institute (2007) reinforced the potentially far reaching socio-economic impact of commodities substitution in developing countries, as well as the opportunity opened by nanotechnology enhancement of certain materials. Sarma and Chaudhury (2009) analyzed the possible impacts of a nanotechnology induced shift in copper trade of two copper-dependent countries, Chile and Zambia. Considering current R&D that can cause substitution of this raw material, the authors conclude that those countries will likely experience negative consequences, such as loss of employment.

Off shoring

The most industrialized have the stronger capabilities in nanotechnology, and it is highly likely that they retain the most skilled nanotechnology jobs, but they may not keep all the jobs. Companies have been exploring the advantages of off shoring, such as cheap labor, lower taxes, new markets, and proximity to raw materials sources, for a long time. The emergence of nanotechnology may reinforce this process and add some new features. A survey conducted by NCMS 2010, p. 18) in the US indicates that 30% of the 270 respondents of nanotechnology companies are already involved to varying degrees in off shoring. Several nanotechnology consumer products in the PEN (2010) inventory are manufactured in other countries than the company's headquarters. According to Roco (2010), off shoring is restricted to less complex nanotechnology production.[28] Others, however, suggest that R&D, or at least development activities, can be outsourced or relocated to take advantage of the existing well trained scientific personnel in several developing countries (Foley and Hersam 2006). For instance, China, with its rising performance in nanotechnology research and commercialization, combined with its cheap labor and increasing opening to foreign capital, can become a significant player in nanotechnology production, and in the global nanotechnology labor market (Appelbaum et al. 2008). Another factor at play regarding companies' relocation of production is regulation. As countries enforce nanotechnology regulation in the near future, some nanotechnology production could be directed to countries with less rigorous requirements. Although it is too early to assess these movements, it is highly possible that these complex and often contradictory trends change the global division of labor.

New technologies are introduced to advance competitiveness and elevate profits. This can be achieved though more efficient production technologies, making available better and cheaper materials, and reducing the labor force costs. As the previous

[28] Personal Interview, Dec. 1, 2010.

examples have shown, these processes generally occur at the same time, and they have effects such as reducing jobs and changing the geographical distribution of employment. Counter-movements can come as a result of an expansion of the consumer capacity for more and newer products by the world population.

Conclusions

Nanotechnology is moving toward manufacturing. Maybe not at the fast rates expected at the beginning of the last decade, but advances are tangible. The number of companies developing and commercializing nanotechnology-enabled products is rising. Nanotechnology market has shown a sustained increase over time. As surveys carried out in several countries show, this process is only starting, and most companies will be commercializing more products in the coming years and introducing more complex innovations. Accompanying this process, nanotechnology-related jobs are not restricted to the R&D labs anymore, but encompassing a broader set of activities in manufacturing and marketing.

The speed in which this incipient nanotechnology labor market will increase depends on a series of factors, besides the recovery from the current economic recession. Of particular importance are the ability of firms in overcoming some technical barriers in nanomanufacturing, the reduction of costs of nanotechnology instruments and materials, and the capacity of nanotechnology products to substitute other products, which will depend on consumer's perception of nanotechnology risks and advantages, and their relative costs.

As with any other new technology, nanotechnology will bring about substantial changes in the nature of labor, the skills required, the demand for labor force, and the allocation of workers in a reconfigured industrial structure. Although very scarce, some available studies show that nanotechnology development has already started to affect labor. Given the potential for change entrenched in current nanotechnology R&D, its effects on labor may be far reaching in the near future. As the long theoretical debate on technology and employment has shown, this relationship is not straightforward, but permeated by several factors. On the other hand, as history of technological change has shown, technology-driven effects on labor are far reaching and troublesome.

The early assessment of nanotechnology implications for labor is crucial both for training an appropriate labor force, and to work out policies to deal with the disruptive social consequences that may arise. Far from being a factor for dismissal of the subject, the prevailing small size of the nanotechnology labor force should be taken as a rich laboratory to study and anticipate such issues.

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