Missing pre-requisites from nanotechnology research studies in the global scale: Firms, products and data

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Abstract

Over the past decade, being a continuously emerging industry and fast becoming the next technology revolution, nanotechnology has received commendable as well as non-commendable reviews on its contributions and potential destructions by various pundits and critics globally. Research activities have also strengthened worldwide and its applications have expanded throughout many economic sectors; making it currently a multi-sectoral technology instead of a standalone industrial sector. Scientific contributions have produced significant impact and are incessantly bringing new breakthrough inventions to the public interest; and even though potential uses of nanotechnology are immensely available, on the contrary, potential destructions are yet to be experimented, diagnosed, certified and brought forth to the people’s awareness. All this is considered imperative information to the future evolvement of technological research. This paper detects the missing definitions and key features that should be considered as essential ingredients for further research on nanotechnology with respect to firms, products and data. These aspects have not yet been given sufficient deliberation by researchers. Thus, numerous types of research have been published in the past without taking into account these following aspects. Therefore, this paper offers propositions for future directions in nanotechnology in terms of firms, products and data.

Keywords: Data, firms, nanotechnology, products, propositions.

I. Multifarious And Revolutionary Benefits Of Nanotechnology

Prior to proposing future directions in nanotechnology, it is vital to first and foremost understand and assimilate what nanotechnology really means. Nanoscience refers to scientific activity that occurs within the range of 1–100 nanometers\(^1\). It is a breakthrough

\(^1\) 1 nanometer is one-billionth of a meter; in comparison, the width of a single human hair is approximately 80,000 nanometers) and is
innovation that has evolved from micro to nano. Devoid of joining both nanoscience and nanotechnology terms together to form a whole new term that probably would have resonated as ‘nanoscientech’, researchers worldwide have accepted the use of the term ‘nanotechnology’ instead, since both terms involve nanoscale and share a common prefix which is ‘nano’. According to the Royal Society and The Royal Academy of Engineering Report (2004), ‘nanoscience’ is concerned with understanding some phenomena (such as surface tension/properties, quantum effects, molecular assembly) and their influence on the properties of material, whereas ‘nanotechnology’ aim to exploit these effects to create structures, devices and systems with novel and significantly improved properties and functions due to their size.

To put it succinctly, nanotechnology is the application of nano-scientific developments that could deliver revolutionary advances that could transform or replace existing products and industries and create entirely new ones which are lighter, faster, cheaper, safer and multi-functional (providing many capability features). This radical technology and continuously emerging industry known as nanotechnology, exploits the ultra-diminutive size, enabling the use of particles to deliver a range of profound and overriding benefits that include new prevention and detection, medical treatment technologies to reduce the rate of deaths and suffering from diseases like cancer and other deadly diseases, self-healing materials, new organs to replace damaged and diseased ones, clothing that protects toxins and pathogens, stain resistant clothing, clean and inexpensive renewable power through energy creation, storage and transmission technologies, universal access to safe water through portable, inexpensive water purification systems, energy sufficient, low emission “green” manufacturing systems, high density memory systems that is capable of storing the entire universal library collection, improve health and nutrition, reduce global hunger and malnutrition; powerful, small, inexpensive sensors that can warn of minute levels of toxins and pathogens in the air, soil and water and alert the people to sudden changes in the environment, health and fitness items, lighter weight auto parts, lighter weight cars that requires less fuel, cosmetics, sunscreen, its contributions to national defence and space exploration.

As far as new firms and incumbents are concerned, nanotechnology can be thought about as a disruptive technology that improves, although

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2 Disruptive technology is a term invented by Harvard Business School Professor Clayton M. Christensen to describe a new technology that unexpectedly displaces an established technology. In his 1997 best-selling book, "The Innovator's Dilemma," Christensen separates new technology into two categories: sustaining and disruptive. Sustaining technology relies on incremental improvements to an already established technology. Disruptive technology lacks refinement, often has performance problems because it is new, appeals to a limited audience, and may not yet have a proven practical application.
doesn’t wholly replace the existing system; but has the capability to adapt with the existing system and therefore two technologies can be acclimatized together to become one. To put it laconically, it has impacted on firms in a way that it has changed the way people deal with things. Another important aspect bracketed together with nanotechnology is its multidisciplinary nature, which makes it very intricate to pin down and presage the future impact in any specific sector aptly (Bhat, 2005) and as such its applications will stretch through many economic sectors with diverging magnitude and formations of impact on existing firms and industries (Shea, 2005). In light of the foregoing, this research paper offers propositions for future directions in nanotechnology in terms of firms, products and data.

II. The Subsistence of Nanotechnology: How Long Has It Existed?

There is a serious misconception or a belief that nanotechnology is only now becoming the next big industry after information technology, biotechnology and the convergence\(^3\) of the two which is the bioinformatics revolution. Nanotechnology is in fact built on a long history of technology much older than is widely believed; and other than researchers, only a handful are familiar of its existence. In 2004, North Carolina State University conducted a telephone survey of 1536 adults and found that 80% of the respondents knew little or nothing about nanotechnology (Austin, C, 2004). The following year, in 2005, according to the University of Texas Pan American (UTPA), the percentage of respondents from a total of 978 students who knew what nanotechnology was only 17% (Sheetz T. et al, 2005). However, nanotechnology products have been in the commercial market for centuries. Perhaps the first product based on “bottom-up” nano-properties of a material was carbon black (Romig et al, 2007). Many researchers persistently describe nanotechnology as an “emerging industry” even though they are cognizant that it has been around long before our time. This is why Romig, et al (2007) question policy makers as to: ‘why do we see these technologies as “emergent”?’ when they actually aren’t. The existing verities simply reaffirms that nanotechnology should no longer be hailed an embryonic (emerging) industry but be referred to as a mature (established) industry which have derived many beneficial products and innovations which are far lighter, faster, cheaper and safer weighed against to what we had before. Nanotechnology was enunciated by Professor Richard Feynman on 29 December 1959 who described molecular machines building with atomic precision in his talk entitled “There is a plenty of room at the bottom”. Feynman, the Nobel Prize Winner in Physics did not pronounce the exact term ‘nanotechnology’ but accurately described its potential for extreme miniaturization and the self-organizing and self-assembly of molecules. The term ‘nanotechnology’ was only then verbally introduced by Professor Norio

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\(^3\) Examples of convergence technologies include molecular machines comparable to the natural machinery inside living cells, medical devices and materials that might be implanted inside the human body, and the application of principles from computerized natural language processing to genomics and proteomics (Roco and Bainbridge, 2009).
Taguchi in 1974. Taguchi used the word to describe the ultra-fine machining which is the processing of material to nano scale precision. In 1977, K. Eric Drexler derived molecular nanotechnology concepts at MIT based on bottom up molecular manufacture, popularized in his book “Engines of Creation” which was published in 1986. The first technical paper on nanotechnology was published by Drexler in the Proceedings of the National Academy of Sciences USA in 1981. Soon after, the world welcomed the advent of the Scanning Tunneling Microscope (STM) by IBM researchers H. Rohrer and G.K. Bining 1981, the unearthing of the buckyball (fullerene) in 1985, the atomic force microscope (AFM) in 1986 and crystal carbon nano tubes in 1991. Ever since, there have been significant discoveries of nanotechnology products and there are others being introduced either radically or incrementally.

III. Nanotechnology Firms And Products

Firms in the US, Europe, Japan and South Korea are all attempting to successfully pave way into becoming precursors of nanotechnology. The United States, Western Europe, Japan are among the developed countries that show a dominant force in nanotechnology research. Following in close lead are the developing countries like India, China and South Korea. Malaysia is also augmenting its efforts to make its mark in the global arena. As of 2008, more than 600 nanotechnology products were in the market, generally offering incremental improvements of existing products; more than half of which have been produced by companies based in United States4. The Project on Emerging Nanotechnologies (PEN 5 )’s Nanotechnology Consumer Product Inventory has found that the number of manufacturer-identified nanotechnology-enabled consumer products that have entered the marketplace to date has increased to over 1,300. However, this number is not yet comprehensive because it has been difficult to find out how many “nano” consumer products are on the market and which merchandise could be called “nano”. Therefore, the question arises as to “Which products can be justified as nano products?” According to Lux Research6, it is estimated that products

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4 According to the Science and Technology Policy Resources (2008), the United States launched its first national nanotechnology initiative (NNI) in the year 2000. Following the creation of NNI in the year 2000, more than 60 nations have established their own national nanotechnology initiatives. In terms of investments amounts, the United States leads other countries by investing USD 3.7 billion through its National Nanotechnology Initiative (NNI) followed by Japan with USD 750 million and European Union with USD 1.2 billion in investment.

5 Project on Emerging Nanotechnologies (PEN) was established in 2005.

6 Lux Research was founded in 2004 as a spin-off of venture capital firm Lux Capital. Today Lux Research is fully independent; Lux Capital is a minority shareholder and the two firms have no operational links. Lux Research is a research and advisory firm that provides strategic advice and on-going intelligence for emerging technologies. They evaluate relevant technology applications in their industries, prioritize technologies, collaborators, and markets, continuously monitor innovators, competitors, and customers, connect with partnership or acquisition targets and tify
incorporating nanotechnology produced $50 billion in global revenues in the year 2006 and by the year 2014, revenues will reach $2.6 trillion of projected global manufacturing output (Science and Technology Policy Resources, Science and Industry Division, 2008).

A rough estimate of the number of companies focusing on nanotechnology related work worldwide currently is around 550, including large companies that have opened up units devoted to this field, as well as start-ups and smaller companies (Bhatt, 2005). It can be conjectured that Bhatt’s rough estimate of 550 was based on the Technology Transfer Center Reports and did not account for the number of companies in the United States. According to the Technology Transfer Center (TTC, 2007), there are over 300 nanotechnology companies in Europe with over a third of which are based in Germany (approximately 40%); with a total of 120 companies; followed by United Kingdom (approximately 23%) with a total of 70 companies, Switzerland (approximately 7%) with a total of 20 Companies, France (approximately 6%) with a total of 18 companies and 250 companies in the Asia Pacific. All firms measured by TTC comprise of a unification of nano product manufacturers, nano distributors, nano R&D laboratory based companies and mere subsidiaries of large manufacturing nano groups. In succinct form, the figure provided by various sources also includes non-manufacturers of nanotechnology. Therefore, this figure cannot serve as a viable measurement of what the actual number of companies involved directly in the area of nanotechnology really is.

Based on the Project for Emerging Technologies (PEN) Report, there are 1200 nanotechnology companies across United States. In negation to this statistic, according to the United Kingdom’s Department of Trade and Industry (DTI)’s report on nanotechnology companies in 2010, there are 4934 nanotech companies in the United States (approximately 33%), 2144 companies in Germany (approximately 14%), 1946 companies in Japan (approximately 13%), 770 companies in United Kingdom (approximately 5%), 726 companies in France (approximately 4%) and 4325 companies across other countries (approximately 29%).

This just corroborates the fact that in the past decade, individual researchers and research based governmental organizations have provided contradictory and inconsistent statistics on the number of nanotechnology firms that exist today across the globe. Perhaps, it is due to the fact that each researcher prescribes their own definition of what a “nanotechnology firm/company” really means. Be that as it may, none of these researchers have recorded their definitions in their reports and publications as to how they define a “nanotechnology firm/company” based from their own standpoint and assumptions. Hence, until today, there is neither a standard definition nor characterization for a “nanotechnology firm/company”.

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revenue streams in new and non-obvious markets. Lux Research analysts are a diverse mix of consulting professionals, market researchers, and Ph.D. scientists and engineers. (Lux Research, 2008)
Therefore, this discussion leads to the following propositions:

**Proposition 1: Nanotechnology Firms**

Prior to measuring the number of nanotechnology firms by sector or by location/country, it is imperative to specify the exact and clear definition of a “nanotechnology company/firm” by government regulators to ensure consistent measurement of nanotechnology data in the future. A series of questions to address this issue is:

- Does a “nanotechnology firm” need to actually manufacture nanotechnology products? Or do these companies also comprise of regional distributors for local and foreign companies that manufacture these products? Or do these companies need to have invested on a R&D lab for nanotechnology? Have they specifically been created to develop nanotechnology? Or are they mere subsidiaries of large companies or industry groups? Once these questions have been dealt upon, then a clear and comprehensible definition will be attained of what a nanotechnology company really is.

**Proposition 2: Nanotechnology Products**

There are products which are labeled “nano” but do not necessarily embed any nano components inside. Due to this fact that it has been difficult to compute for how many “nano” consumer products are there on the market and which merchandise could be called “nano”. There should be a fixed criterion and requirement that a product needs to comply with in order to be categorized as a nano product. There should be an explicitly stated specification of what percentage (%) of nano component needs to be embedded in order to be declared as a nano product. Therefore, this leads to the following question “Which products can be justified as nano products? and “how do you designate a product as nano?” In order to solve this dilemma, a comprehensive definition of what ‘nano products’ really means should be realized and with the intention that, in the future, data measured by funded research groups, independent bodies or governmental organizations will be consistent and in line with the prescribed definition.

**Nanotechnology Data Deficit**

Even though information on the potential uses of nanotechnology is immensely available, however, a comprehensive assessment of measuring the competitive position of the United States in regards to nanotechnology is unfeasible at this time. (CRS Report for Congress, 2008) Nevertheless, the fact that United States still remains a global leader in nanotechnology has been accepted as true by many experts. Thus, there has not been any data collected (such as the actual revenues, market share and trade) to assess nanotechnology. Currently the forecasts are only available. A matter of fact there is no quantitative data on nanotechnology from any countries worldwide on time series basis sectorally. The only available indicators are public and private research inputs, scientific papers and patents; however these may not prove to be unswerving indicators because basic research in nanotechnology may not translate into viable commercial application; in view of the fact that basic research can take decades to result in commercial
applications and scientific understanding may not provide commercial opportunities. Nevertheless, national research and development investment in science and technology is an input measure to translate R&D results into commercial products, guaranteed there is capability of scientists and engineers conducting the R&D. Even though data for investment in national research and development is available; but until today, there is no statistical source that can vouch for the number of scientists and engineers involved in nanotechnology globally. At the present time, there has not been any data on the number of student enrollments, number of degrees conferred in the area of nanotechnology in universities and colleges if any. Likewise there has not been any data on the number of nano related job openings and corresponding wages existing to date. However, quantitatively through a text mining study (2003 – 2005), the number of scientific papers on nanotechnology and nanoscience contributed by each country has been statistically measured by Porter and Cunningham (2005), Kostoff, Koytcheff and Lau (2007), Kosumi and Nazrul Islam (2007;2010). Nevertheless, an unyielding challenge posed towards data anthology is due to its multidisciplinary nature which causes it to be borderless. Five (5) out of seven (7) published papers propose different delineations of the codified nanotechnology knowledge base (papers and patents) (Bozeman, Laredo, Mangematin, 2007).

At this point of time, nanotechnology has been found to be dispersed within various industrial sectors; given the fact that nanotechnology is currently a multi-sectoral technology and has not been made a single industrial sector (not a stand-alone sector) classified under Nomenclature Generale des Activites Economiques dans l’Union Europeenne (NACE), US Standard Industrial Classification System (US SIC), United Nations Standard Industrial Classification System (UN SIC) and the North American Industry Classification System (NAICS Canada). NAICs includes 1,170 industries and SIC includes 1,004 industries. There are 358 new industries recognized under NAICS and 250 of service producing industries (Department of Revenue Washington State, 2010). It has been identified that 800 over nano related firms are associated to 40 NAICS codes. That is why nanotechnology has not been included in its key findings by statistical organizations worldwide as a specific industry. There is no industrial classification that exists for nanotechnology. What is available are only the general and standardized censuses carried out annually which adheres to the following international classification systems. Nonetheless, under the International Classification System by the World International Patent Organization (WIPO), nanotechnology has been acknowledged as a field of technology converged with microstructures under the technological wing of chemistry.

**Proposition 3: Data Accessibility**

Time series data on the total number of employees, sales turnover, total assets of nanotechnology firms are the types of information that need to be generated by statistical organizations in total and sectorally. Even if the number of nanotechnology firms in some countries
still remain small, it is vital for governments to keep track of its growth through continuous measurements each year. In addition to this, measurements need to be in line with Proposition 1.

Proposition 4: Standalone Industrial Sector

Nanotechnology needs to be acknowledged as a single industrial sector under the NACE, US SIC and NAICS industrial classification systems.

IV. Conclusion

In closing, this paper concludes that the standard definition of what a “nanotechnology firm” constitutes is still not available. The fact that numerous statistical measures have been undertaken in measuring the number of firms existing worldwide; the figures remain incomprehensive and incomplete with the absence of this key definition. Flanking this issue is another aspect, which is what constitutes a “nano product”. Thus, these definitions have been missing from intellectual debate in the past and present. It is pointless for rich organizations to conduct studies on measuring nano firms and nano products available worldwide without a thorough and comprehensive definition of the two. Also, there has not been any data on the actual revenues, market share and trade, number of student enrollments, number of degrees conferred in the area of nanotechnology in universities and colleges, number of nano related job openings and corresponding wages existing to date. Findings also show that nanotechnology is currently a multi sectoral industry and not a standalone industry; meaning data specifically for the nanotechnology industry is not readily available an immensely scattered between various sectors. These propositions need to be embraced immediately to ensure future consistency.

References

Austin C. (2004) Study shows Americans encouraged by prospects of nanotechnology as cited by Sheetz et al (2005) Nanotechnology: Awareness and Societal Concerns, Technology in Society, 27 (3), p329 – 345

Bhat, Jyoti S.A. (2005) Concerns of New Technology Based Industries – The Case of Nanotechnology, Technovation, 25 (5), pp.457-462.

Bozeman. B. et al (2007) Understanding the Emergence and Deployment of “nano” S&T, Research Policy, 36 (6), pp 807 – 812

Christensen, Clayton M. (1997) The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail. Harvard, MA: Harvard Business School Publishing Corporation.

Department of Revenue Washington State (2010) SIC and NAICS Codes Available from: <http://dor.wa.gov/content/aboutus/statisticsandreports/sic_vs_naits.aspx>[Accessed 09/05/2011]

Kostoff, Ronald.N. et al (2007) Global Nanotechnology Research Literature Review, Current Science, 92 (11), pp 1492 – 1498

Lux Research (2008) Nanomaterials State of the Market (Quarter 3)

Miyazaki K., Islam N. (2007) Nanotechnology Systems of
Innovation – An Analysis of Industry and Academia Research Activities, Technovation, 27 (11), pp 661-675

Miyazaki K., Islam N. (2010) An Empirical Analysis of Nanotechnology Research Domains, Technovation, 30 (4), pp 229 – 237

Porter, A.L, Cunningham, S.W. (2005) In Tech Mining: Exploiting New Technologies for Competitive Advantage

Romig A.D. et al (2007) An Introduction to Nanotechnology Policy: Opportunities and Constraints for Emerging and Established Economies, Technological Forecasting and Social Change, 74 (9) pp1634-1642

Royal Society and The Royal Academy of Engineering Report (2004) Nanoscience and Nanotechnologies: Opportunities and Uncertainties. London, UK: The Royal Society.

Shea, Christine.M. (2005) Future Management Research Directions in Nanotechnology: A Case Study,

Journal of Engineering and Technology Management, 22 (3), pp 185 – 200

Sheetz T. et al (2005) Nanotechnology: Awareness and Societal Concerns, Technology in Society, 27 (3), pp 329 – 345

Technology Transfer Center, Institute of Nanotechnology (2007) Government Funding, Companies and Applications in Nanotechnology Worldwide (figures taken from Nanotechnology in Europe (2007) and Nanotechnology in Asia Pacific (2007)), Nanopost.com

United Kingdom. Department of Trade and Industry (DTI) Report (2010) Nanotechnology: The Companies Involved cited from Nanotrend Newsletter, November 3, 2010

United States. Science and Technology Policy, Resources, Science and Industry Division (2008) CRS Report for Congress, Nanotechnology and U.S. Competitiveness: Issues and Options, May 15, 2008