Engaging with the public? Assessing the online presence and communication practices of the Nanotechnology Industry

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Abstract

This paper examines whether the nanotechnology industry is engaging in the wider social debate surrounding it, through an analysis of its online communication practices. This is an important topic to study given the nascent nature of the technology and the concerns among proponents to avoid the backlash biotech companies faced over GM crops. Applying a new web crawling tool, the study captures and codes the hyperlinks of key nanotechnology companies according to their social and technical orientation, and status as producers, disseminators, commercializers. The links are mapped and the prominence of social and technical issues assessed. Finally, the home pages of sites are content-analyzed to contextualize the presentation of the debate. The results show that while parts of the scientific community may have accepted the case for more engagement with the social aspects of nanotech, commercial developers are more reluctant to do so, at least based on their online presence.

Key words: Nanotechnology, social risk, science communication, online networks, hyperlink analysis, cybermapping

Introduction[1]

A question asked with increasing frequency by academics, policymakers and industrial experts is whether nanotechnology will prove to be the "next GM"? (Keller, 2007; Macoubrie, 2006; Waldron et al, 2006), an exciting new technology that is heralded for its potentially enormous economic and social gains and then flatly rejected by consumers fearful of its health and environmental effects. So far the issue has assumed a relatively low public profile in most countries. Yet, the notable successes of anti-biotech campaigners in Europe and creeping references to 'grey goo' and 'frankenfoods' in the media [2] indicate the importance for nanotechnology promoters to get on the 'front foot' in shaping public debate surrounding its development and allaying popular concerns. To date, this challenge appears to have met by the policymaking and scientific communities who have issued explicit calls for greater openness and transparency in communicating its risks and benefits and the need for more "upstream" methods of public engagement on developments within nanoscience (Wilsdon and Willis, 2004; Macnaghten et al, 2005). The extent to which the nanotech industry itself is engaging with this wider educational mission, however, is less clear. As the primary investors and developers of the technology one might expect logically that they would be somewhat reluctant to openly discuss the risks and any security considerations associated with its wider roll-out. However, the particular sensitivities of the post-GM environment combined with the mounting pressure from public bodies to promote greater social awareness about nanotechnology clearly create incentives for the industry to engage in this wider public dialogue. Moreover, such moves also fit well within the new climate of 'corporate social responsibility' which has emerged across the past two decades in the business world and seen companies shift toward finding more ethically-based profit models (CSR) (Crane et al., 2008).

This paper seeks to address the question of how far the key developers and promoters of nanotechnology are engaging with the call for a more socially responsible communication strategy. It does so by using original data from the World Wide Web (WWW), focusing particularly on the web links surrounding the key investors and developers of nanotech and the messages contained within their home pages. In focusing on the online presence of these organizations, we recognize that we present only a partial picture of their wider communications efforts. However, by 2007 when the investigation was conducted the online arena had become a crucial arena for global communication and commerce and more closely integrated into individuals' and organizations' ‘offline’ activities (Haythornwaite & Hagar, 2005). Furthermore, homepages and hyperlinks can be seen to constitute highly efficient and low-cost methods for groups to build networks and communicate their wider purpose, particularly one might argue for those within the science and technology sectors. Finally, these data and the methodology used to collect them constitute an important new approach to understanding and analyzing web networking which we hope will provide new insights and guidance to future work in the area of online communication by business as well as other types of social and political actors.

As well as presenting an innovative approach to understanding this new industry's permeability to a wider ethical agenda, this study also carries potentially significant policy implications. Our results will provide a unique insight into whether the nanotech industry is responding to government expectations on the public engagement front. If they are not, then the question is raised of whether more direct measures to promote their activities in this regard are required. As Keller (2007) has noted, to date the nanotechnology industry has experienced a relatively 'light-touch' approach by governments. Its multi-disciplinary nature (spanning physics, materials science, mechanical and electrical engineering, genetics and cell biology) has recommended a flexible, staged and iterative approach to regulation. Whether such independence can continue if the industry is found to be failing to engage in the dialogue over the social implications of its activities clearly becomes a relevant matter for public authorities to consider.

Reaching Out: The Nanotech Industry, Government and the Public

The rise of nanoscience and the nanotechnology industry clearly poses new challenges for governments, professional bodies and producers to develop appropriate regulatory standards, both on the national and international level. Indeed, global harmonization of standards will be of increasing importance given the growing worldwide trade in nanotech products and potential cross-border environmental hazards (IFAS, 2007). Internal and cross-governmental coordination to monitor and manage the roll-out of nanotechnology, however, is not the only arena where effective communication and networking is required. Wider external efforts to engage with non-specialist audiences and the public more generally are also of increasing relevance, particularly in light of the recent and very highly publicized backlash against the biotechnology industry in its bid to introduce GM crops in Europe (Better Regulation Task Force, 2003; ETC Group, 2003; Mayer, 2002; Mnyusiwalla et al, 2003; Rolison, 2002).

So far, it is “early days” in nanotechnology’s development, at least as a public issue. Consumer products featuring nanotech (either in name and/or content) are only just beginning to be marketed in Europe and levels of public awareness of nanotechnology are extremely low (Cobb and Macoubrie, 2004; Dowling, 2004; Macoubrie, 2006; Scheufele and Lewenstein, 2005; Waldron et al, 2006;).[3] There are signs, however, that the emergent issue cycle exhibits some parallels to the ‘GM’ debate in that the public are forming views on the risks and benefits of nanotechnology in a range of areas including health and environment, despite professing to know very little (Macoubrie, 2006; Cobb and Macoubrie, 2004; Kearns et al, 2006). The common cognitive shortcuts used by individuals in forming these opinions, although they include general orientations to science and technology, stem from specific experiences with previous technological ‘breakthroughs’ and levels of trust and confidence in government to manage risks (Lee et al., 2005; Siegrist et al, 2007; Macoubrie, 2006; Cobb and Macoubrie, 2004), factors that would suggest a high likelihood for attitudinal instability and change. Mass media representations of emerging technologies are also relevant in this opinion formation process (Scheufele and Lewenstein, 2005). Research on the reporting of genetics and biotechnology research has shown how this can shift in response to wider ideological debates and international events (Hansen, 2006; Cook et al, 2006). Thus, while the coverage and reception of nanotechnology may have been generally positive so far (Anderson et al, 2005; Stephens, 2005), this is potentially subject to change.

Given the uncertain and dynamic context surrounding the public understanding and acceptance of nanotechnology, it is perhaps no surprise that governments, scientists and business have moved onto the front foot to address popular concerns about its social, ethical and environmental implications. Certainly, the scientific and regulatory community, in the shape of academic researchers and national and international government bodies, are approaching the issue with an understanding of the public-as-key-stakeholder (NSF, 2001). Worldwide research and development (R&D) into nanotechnology has risen rapidly in recent years. Government organizations alone were reported to have increased their investment more than six-fold from $430 million to $3 billion across the period 1997 to 2003 with 35 nations having established a national nanotechnology initiative during this time period (Roco, 2003). Under the European Commission's 7th Framework Funding Programme launched in 2007, a special stream for Science in Society was established in which nanotechnology figures prominently. In the US substantial funding for large-scale research into societal aspects of nanotechnology has been made available under the National Nanotechnology Initiative (NNI), with approximately $80 million be made available for study of the educational and societal implications of nanoscale research. From the start, the NNI 'considered societal implications…an integral part of the process.' (Roco, 2003: 185) and in 2006 one of the largest grant awards in social science in the US was made to establish Centers of Nanotechnology in Society at the University of California, Santa Barbara and Arizona State University. The Center's stated mission being "to serve as a national research and education center, a network hub among researchers and educators concerned with nanotechnologies' societal impacts, and a resource base for studying these impacts in the US and abroad." (http://www.cns.ucsb.edu/about-cns-ucsb/).

In the UK, while government funding has not proved as generous as in the US, strong statements about the need to ensure widespread public engagement with nanotechnology at an early stage have been made in a variety of reports and documents issued by esteemed professional bodies including the Royal Society, the Royal Academy of Engineering (Dowling, 2004) and the National Research Councils. This explicit commitment, as Macnaghten et al (2005) explain, can be linked to the UK's particular historical context and the series of controversies that have emerged in recent years over GMOs and issues of food production, such as the BSE crisis and the 2005 foot and mouth outbreak which contributed to public suspicion of the science and technology industry and further mistrust of government's handling of such issues.

One of the key questions raised by this high profile investment in the societal dimension of nanotechnology is how far it is being delivered in practice by its major developers. According to some recent accounts, the message does not as yet appear to be strongly in evidence in the sector. In particular, commercial and business sponsors of the technology appear to have been somewhat less enthusiastic to talk about the social aspects of nanotechnology and advance public understanding of the issues. A recent editorial in a specialist journal accused the small to medium sized enterprises that dominate the nanotech industry of remaining 'largely silent of the risks of nanotechnology' (Editorial, Human and Ecological Risk Assessment, 2006: 814). While it is accepted that this may result from the inevitable size and resource constraints that such business face in undertaking public outreach activities, the lack of effort in this regard is clearly a source of concern. Of course, instances of good practice have also been identified, with the US Chemical Industry coming in for particular praise for establishing a Nanotechnology Panel in partnership with Environmental Defense (ED) to issue a Joint Statement of Principles on the potential risks that government should consider in relation to the manufacturers of the technology.

The extent to which these contrasting accounts represent the stance of the wider industry in communicating the health, environmental and ethical issues of nanotechnology is an important question, given the rhetorical and financial commitment that accompanied its development so far. As yet, however, it is one that has not been the subject of extensive and systematic investigation and is the subject for analysis of this paper.

Online Communication: Hyperlinks and Homepages

In order to address the extent of commitment to public or societal outreach among the developers and producers of nanotechnology we use evidence from the communicative efforts they are making in the online environment. Specifically, we utilize web crawling and hyperlink analysis tools in order to gain a picture of the connections being developed by the nanotech industry and particularly the extent of their links to a wider public sphere. We then examine the contents of the home pages of the range of actors involved in the nanotechnology debate, revealed through the hyperlink analysis phase of the data collection. In this section, we outline the significance of these data for addressing the key questions in our study.

The hyperlink is commonly seen as the essence of the web (Foot et al 2002), establishing its structure and value (Bar-Ilan 2004; Ingwersen 1998) and reflective of communicative and strategic choices on the part of site producers (Rogers and Marres, 2000). Kleinberg (1999) refers to web hyperlinks as “conferrers of authority” or endorsement, while Davenport and Cronin (2000) argue that hyperlinks reflect trust and produce associative relations between actors (Barbules and Callister, 2000). Developing these arguments, Park et al. (2005), and more recently Ackland and Gibson (2009), have identified a series of functions that hyperlinks can be said to perform:

- Information provision – at their most basic level hyperlinks lead to new sources of information.

- Network building or strengthening – in addition hyperlinks work together to establish patterns of linkage and association between social and political actors that can reflect existing networks or build new ones.
- Identity/image building or ‘branding’ – hyperlinks signal endorsement and recognition of other groups/agents’ messages and, thereby, form shortcuts to the outlook/views of site producers.
- Audience sharing – hyperlinks promote the rapid transference of internet users around the Web.
- Message amplification or ‘force multiplication’ – dense and highly self-referencing hyperlinks between groups sharing a cause or outlook can magnify or exaggerate their presence to users. This can be a particularly useful function for weaker or more marginal actors such as the far right in the offline world (Gerstenfeld et al. 2003; Whine, 2000).

Given the range of communicative and organizational functions that hyperlinks can perform, their analysis in the context of this study is expected to yield significant insights into the outreach efforts of the nanotechnology industry. In particular, their use of hyperlinks is used to assess:

- What further sources of information the nanotech industry is disseminating/promoting to its audience? Specifically, who the producers and developers of nanotechnology are linking to in terms of their role in the nanotechnology debate, and their social versus technical/scientific orientation toward the debate.
- Whether the nanotech industry constitutes, or is part of, an online network? If so, are other organizations involved and who are the most prominent and peripheral players? Does the network confer more authority on the more technical and scientific proponents in the debate or does it also promote the voices articulating wider discussion of the ethical/environmental/ health risks?

Once the informational and networking aspects of the nanotech industry's hyperlinks have been mapped, a further stage of data collection is undertaken that examines the contents of their sites, and those they link to, in more depth. Specifically, the meta keywords contained in the home pages of these sites are captured and categorized in terms of the extent to which they are associated with social and technical sides of the nanotechnology debate. Details of the data and methods used for both the hyperlink and content analyses as well as the key findings from each are provided below.

Hyperlink Analysis

To investigate the questions regarding linking practices of the nanotechnology industry, we applied the web crawler that is part of the VOSON System (Ackland, 2007).[4] A problem that is often faced when using web crawlers to construct web network datasets is: where to start the data collection, i.e. what "seed sites" should be used as the starting point? For this paper, the starting point was the corporations involved with nanotechnology development, in particular, the 25 corporations on the Merrill Lynch nanotechnology index (these are corporations that have a significant percentage of their future profits tied to nanotechnology) at the time of the data collection (March 2007) – see Table 1.[5]

Web crawling and site classification

The websites of these 25 companies were crawled using the VOSON web crawler (this identified pages that are linked to by these corporate websites) and the Google API was then used to find the pages that link to these corporate websites. After this data collection, the database contained 2,772 web pages. It should be noted that while the unit of data collection is the web page, for the unit of analysis is the website i.e. we aggregate the pages that are hosted on the same web site (the 2,772 pages are hosted on 1,135 websites).

In the next stage of the data collection, we created a subset that contained the 25 seed sites plus those sites that are "important" in that they have a degree (indegree plus outdegree) greater than or equal to two i.e. they are connected to two or more of the seed sites. There were 202 seeds plus "important" sites. The 173 new sites identified by this process were then inspected to see whether they are specifically focused on nanotechnology and 22 new sites were identified. These 22 new sites were added to the 25 original seeds and VOSON was then again used to find inbound hyperlinks to and outbound hyperlinks from the 22 new sites. The resulting database contained 11,431 pages (4,458 sites).

As before, a subset dataset that contains the 47 seed sites and 798 newly-identified "important" sites (degree >= 2) was created. It was not feasible to check the 798 new sites identified in this step to see whether they are focused on nanotechnology, and so instead we decided to simply identify the new sites that contained "nano" in their URL; 132 new sites were identified using at this step (these additional sites were also crawled to find who they link to and the Google API was used to find who links to them). The final database therefore contains 179 seed sites; these sites were manually classified along several dimensions.

Where possible, country of origin of the site was determined from the country code top level domain (TLD). Since many of the sites do not have country TLD information (e.g. dotcom sites) we also used the WHOIS service to ascertain the country of origin of the person or company who registered the domain name. The vast majority (109) of the sites are from the US (for 4 of the sites, we could not determined country of origin). The majority (99) of the sites are ".com", while 29 are ".org", 12 are ".net" and 10 are ".edu".

Beyond this automated system of classification we also attempted to classify the sites according to their main activity or purpose in relation to nanotechnology. Three basic activities were identified: (1) production (2) dissemination (3) commercialization. Production refers to companies/ organizations that are either producing nanotechnology itself (or services/equipment relating to this process) or are producing academic research relating to nanotechnology. Dissemination sites are non-commercial sites that are focused on making available research or information relating to nanotechnology that has been produced by others. Commercial sites are for organizations/groups who are not producers of nanotechnology, but are aiming to make money from it, for example by facilitating technology transfer or business consulting services. Each of these major categories had 2-3 sub-categories:

- *Production - technology company.* These are companies that are involved in commercial activities pertaining to nanotechnology e.g. production of nanotechnology products, or equipment/services relating to nanotechnology.
- *Production – knowledge.* These are organizations that are producing research relating to nanotechnology e.g. government/academic research labs, think tanks.
- *Dissemination - academic.* Academic sites disseminating information relating to nanotechnology.
- *Dissemination - basic/blog.* Blog sites focused on nanotechnology.
- *Dissemination - industry.* This category includes industry groups that seek to promote information about nanotechnology.
- *Commercial - consortia.* These are sites that involve partnerships between business, government and/or academia and that are aimed at technology transfer.
- *Commercial - infosites.* These are sites that provide information on nanotechnology and are primarily focused on making money e.g. by business services, consulting, job placement. These sites typically look like portals i.e. they have many links to other sites.

In a second step, sites were also assigned into one of two broad categories according to whether their main focus is on the "technology" side of nanotechnology, that is the science and manufacturing aspects (this also includes business), or the social aspects broadly defined, e.g. including reference to the health, ethics, legal aspects. Both of the nanotech-specific classification schemes were applied via manual coding, with two of the four coders/authors working on each site.[6] Table 2 reveals a fairly wide range of countries featuring in the hyperlink network, although there is a clear predominance of US organizations. The UK as the second most represented country constitutes less than 10 percent of the overall number of sites identified. The 'dot coms' are also by far the most commonly found sites in terms of generic TLDs. More significantly, however, in terms of organizational types, it is the nanotechnology producers that dominate, constituting over half of the overall total of sites found. Disseminators and commercializers are more evenly balanced, with 46 sites engaging in some form of knowledge or information-sharing about nanotechnology and a further 39 explicitly seeking to profit from the technology. Given the strong representation of those producing and commercializing the technology, it is perhaps not too surprising to find that overall, most sites have a technical focus, with less than 10 percent dealing mainly with the social aspects nanotechnology. From this brief snapshot of the websites that are situated in the hyperlink network with the 25 seed websites, it appears that the nanotechnolgy industry mainly uses the web to link to others involved in nano development, with social concerns occupying something of a backseat role.

Hyperlink analysis results

While simple frequencies of the website types in this network can tell us something about the commitment to public engagement by the members of the nanotech industry, they are clearly not the whole story. Although sites focusing explicitly on dissemination of information about nanotechnology or related social issues are numerically less common in the network, it may be that they occupy a more authoritative or influential position than more technically-oriented sites.

Before presenting the hyperlink analysis, it should be noted that it was not possible to crawl five of the 179 nanotechnology-related websites (this might be because the websites were not active at the time of the data collection). Because some of the network measures we present below can only be constructed for a graph "component" (where every node is connected to at least one other node), we decided to drop these five sites (which are all companies involved in nanotechnology production) and hence the final dataset used for the hyperlink analysis contains 174 sites.

Figures 1 and 2 present force-directed graphs (FDG) drawn using the LinLogLayout algorithm of Noack (2005), where the node size reflects the number of inbound hyperlinks to the site.[7] While these maps can really only be used for descriptive (rather than analytical) work, they do provide some useful insights. For example, it is apparent from Figure 1 that although they are small in number, the socially-oriented sites are reasonably well-connected with the rest of the technical-oriented sites; while they form a grouping in the bottom left-hand corner of the map, they evidently have quite a lot of connection to the other sites. From Figure 2, it is apparent that commercial infosites (colored orange) are quite prominent (based on indegree) and central, while commercial producers of nanotechnology (red) are not particularly prominent.

To investigate these structural properties of the nano network further, in Tables 3 and 4, we calculated averages of various measures of site prominence for the different classifications of websites.[8] Of course, given that we only have 13 sites classified as "social", the results in Table 3 need to be treated with caution. One basic measure of network prominence is indegree links, and on that measure social sites appear to be more prominent (indegree of 10.3 compared with the average of 7.5). However, it was noted that one of the sites categorized as social - www.foresight.org - was particularly prominent, and with a sample size of only 13 it is possible that it is exerting undue influence on the sample mean. When the average indegree score was calculated with www.foresight.org excluded, social sites have a mean indegree slightly lower than the average.

Another measure of network prominence is provided by Kleinberg's (1999) Hyperlinked-Induced Topic Search (HITS) algorithm, which is based on the premise of the existence of hyperlinked communities that contain two distinct, but inter-related, types of pages – *authorities* (highly referenced pages) on the topic, and pages that point to the authority pages. The latter are referred to as *hubs* since they serve as central points from which authority is conferred on other authority pages in the community.[9] Social sites have higher authority scores than average (0.067 compared with 0.049), but again, this is largely due to the presence of www.foresight.org (when this is removed the average HITS authority score for social sites is close to average).

The final network measure in Table 3 is *betweenness centrality* which gives an indication of the extent to which an individual node plays a “brokering” or “bridging” role in a network and is calculated for a given node by summing up the proportion of all minimum paths within the network that “pass through” the node.[10] A high score on betweenness centrality indicates essentially that this is a core site in the network and that it is closely linked in a direct way to a large number of other sites. If we find that social sites have high betweenness centrality, then this would indicate a certain level of prominence of social sites within the online networks formed by organisations involved in nanotechnology. The betweenness centrality for social sites is 272 compared with the average of 159, but again this is due to the presence of www.foresight.org and once this is removed then social sites have much lower betweenness centrality than average.

In Table 4, the network measures are again constructed, this time averaging over the “type” of site. The striking feature about Table 4 is that commercial infosites are the most prominent on all three measures discussed above (indegree, HITS authority and betweenness centrality). Thus it appears that although commercial infosites are not actively engaged in nanotechnology and, therefore, are not “authoritative” in the offline sense of producing new products or research relating to nanotechnology, they appear to form a useful and important function online. These sites serve to connect other sites together, thus improving the overall web presence of nanotechnology and enabling information to be found efficiently either via search engines or by users navigating the web. Another finding of interest in Table 4 is that while the technology producer sites are present in high numbers in the network, they are not particularly popular or prominent in terms of their linkage patterns. Producers of research and disseminators of that research are considerably more visible. In addition, blog sites, while not receiving so many hyperlinks from other sites in the network, are highly active in pointing to other sites, as indicated by their high outdegree and hub scores.

A closer insight into the contribution of different websites to the online presence of nanotechnology is gained by looking at the individual websites rankings according to the various network measures. In the upper half of Table 5, we report the findings on prominence of the top 10 sites, ranked according to two key measures – indegree and HITS hubs score. According to indegree measures, the commercial infosites account for 6 of the top 10 sites, with only one socially-focused site (www.foresight.org) is in the top 5. From the bottom half of Table 5, it is apparent that the sites that we have classified as "disseminators" are (understandably) prominent when sites are ranked according to HITS hub scores; half of the top-10 sites when ranked on this measure are disseminator sites. The Foresight website is again prominent, being ranked second on this measure. The composition of the top 10 sites when ranked according to HITS authority scores (Table 6) is broadly the same as the results found for indegree. From the bottom half of Table 6, we see that www.nsti.org (the Nano Science and Technology Institute), a technically oriented site has the highest betweenness centrality score and thus is arguably the most important or core site in the network in terms its connectivity to all other sites.

Content analysis

In addition to the insights offered by the hyperlink analysis into the structure and overall orientation of the online debate about nanotechnology, we wanted to determine more specifically the nature of the social and technical foci of the websites, and how far it linked back to the status and type of site producers in the network. The social versus technical classification used thus far is a binary classification and so somewhat reductionistic; clearly there are sites that would contain elements of both sides of the debate.

To further explore this, we mined the homepages of the sites for key words contained in their meta-tags. Meta-tags are embedded in HTML coding to allow website producers to identify the contents of the site for indexing in search engines. Given their strategic value to reach target audiences we expect the meta-tags to provide insight the types of users the site seeks to appeal to. Through VOSON we extracted the keywords from sites including, roots, variations on the root and plurals (Table 7) and assigned scores to each site based on whether they were present or absent (0/1) rather than their frequency (n). This approach was determined by the fact that we are interested primarily in mapping the nature and distribution of the various technical and social 'discourses' surrounding nanotechnology across websites rather than their overall prominence. For the same reason, we examined only the homepage of each website, which one would expect to contain the main priorities of each organization. Substantively, our content analysis sought to address four questions:

- What 'keywords' are prevalent on nanotechnology websites?
- Do 'keywords' depend on the type of producer of the website?
- Are these 'keywords' structured in discourses about nanotechnology?
- Do these discourses reflect the morphology of the network, specifically in relation to the position of different websites as hubs and authorities?

To answer the first question, Table 8 reports the 22 keywords that we found across our websites that were considered to be nanotechnology-related either in a social and technical manner. As Table 8 reports, *industry*, *science* and *business* top the chart, being found on between a quarter and a fifth of all websites. *Environment* and *health*, follow, contained on one in six websites. Keywords such as *safety*, *future*, *society* and *education* were present on only about one in ten home pages. According to these first set of findings, therefore, it seems that industrial/technical concerns precede social concerns in the framing of the nanotechnology issue. The lack of a wider debate is further confirmed by the low prominence of keywords such as *risk* (9%), *threat* (3%), *ethics* (6%) and *politics* (3%). In the same vein, *discussion* (15%), of a largely scientific nature, prevails on *debate* and *dialogue* (7% together).[11]

In relation to the second question, there is an obvious relation between site producer and the 'slant' of their communication concerning nanotechnology. On the one hand, *industry* and *science* are prevalent on most websites, with peaks on basic dissemination websites and general commercial information sites. Surprisingly, producers of nanotechnologies are not particularly interested in *business* and *investment*, which are largely left to commercialization intermediaries. *Environment* and *health*, again, appear across the board, as general concerns touching all actors involved, including, albeit marginally, producers of nanotechnologies. Overall, it appears that the nanotech producers are extremely limited in their engagement with the issues concerning their products, beyond their industrial / business side. Those websites aimed at dissemination, particularly blogs and academic sites, however, do tend to provide a wider perspective on the social and even political implication of nanotechnologies. Also producers of knowledge related to nanotech also appear open to discussion about the societal side of nano.

Regarding question three, a multi-dimensional scaling of the keywords was conducted, with the aim of further exploring the debate underlying the nanotechnology websites identified here (Table 9). The analysis yielded three main clusters or orientations within the debate, based around the different keywords. The first dimension and the most prominent in the nanotech websphere, is an industrial / proactive discourse. It dwells on the prominence of *business*, *investment* and *opportunity*, largely disregarding *risk*, *safety*, *society*, *health*, and particularly, *discussion*. The second dimension corresponds to a science / education discourse, which strongly emphasizes nano science and features terms such as *industry*, *science* and *education*, while ignoring topics relating to *investment* and *innovation*, as well as *health*, *society* and nano-*threats*. A third strand of debate can be identified that centers on a social / critical discourse, where the risks associated with the technologies are stressed, along with the need of a political discussion. *Industry* is the main, critical focus, discussed along the lines of *safety*, *opportunity*, *environment* and *health*. *News* is prominent, although the *science* and *innovation* aspects of the technology are not featured, and *education* is also seemingly neglected.

The three dimensions of debate are relatively independent, as demonstrated by low correlations between dimensional scales,[12] and as Table 10 reveals, correspond to the social / technical categorization produced by the manual coding. As expected, sites that were identified as 'technical' were more likely to be engaged in industrial / proactive discourse (for this relationship, $\eta = .31$ ***, not reported in table), and socially oriented sites were most strongly linked to the critical / social discourse. The results on this front are not entirely straightforward, however. The technical websites did not shy entirely away from the 'critical/social' discourse and were significantly more likely to participate in the scientific educational discourse than socially oriented sites (although the distance between the two is barely significant, $p = 0.02$ for independent samples t-test). Overall, the results suggest that industrial players engage, albeit to a limited extent, in discussions about the social side of technologies, and definitely engage in science education. Those focusing primarily on the 'social' aspects of nanotechnology, however, are more exclusively inscribed in the social / critical discourse, and overall do not display as close a level of association with the range of discourses identified.

Finally, we were interested in how far the any one discourse dominated the nano-sphere identified in this study. To do this we correlated our individual measures of website hub and authority scores with their scores from the multi-dimensional scaling of keywords. As Table 11 reports, the results are interesting in that overall websites contributing to educational discourse scored more highly on our measures of *authority* position than websites related to other discourses. That is, websites in the network tended to link to sites including the education / constructive keywords to a significantly greater degree than to other sites containing the industrial and critical keywords. Thus, one can argue the science/education discourse is a bridging one regarding the issue of nanotechnology.

Discussion and conclusions

This analysis has focused on examining how well the science and technology world is addressing issues of wider public significance in their development of nanotechnology. Taking in the first instance the core producers of nanotechnology (those companies listed on the Merrill Lynch index plus those identified from the first web crawl), it is clear from a simple division of the social versus technical orientation of their links, and of the sites linking back to them, that the social debate features in only a limited way, and particularly so if one key site (Foresight) is removed. Our analysis discovered that the overwhelming majority of sites starting from this group of producers were technical in orientation.

Application of a more nuanced categorization scheme reveals that outside of the technology producers, it is knowledge producers and also the commercializers of the technology that are the dominant elements of the network in terms of raw numbers of sites. Disseminators – those passing on knowledge and information about nanotech research or products are the least well-represented group. Given that one might expect this ‘mediating’ group to display a greater focus on interpreting the societal implications of nanotechnology, their more limited presence underscores the lower profile of this aspect of the debate within the network identified here.

When we move beyond the basic numerical presence of sites to explore their popularity and prominence within the network, (using the authority, hub, and betweeness centrality scores), a slightly more balanced picture emerges. The socially-oriented sites appear to have, as great, if not greater prominence as technical sites in terms of their inbound links and status as authorities. Foresight, the major think tank on nanotechnology, plays a very strong role in the network, particularly in terms of its role as a brokering or bridging site. This pivotal position is confirmed by its high placement in the individual site rankings on these prominence measures.

The in-depth content analysis of sites, however, largely confirms the lower profile of the social debate across the network of sites connected to nanotech producers. Judging from their homepages and meta-tags, most sites focused on the scientific and industrial aspects of nanotechnology production. Social issues do feature to a degree, particularly in terms of the environment and health. Discussion of risks, ethics and threat play a somewhat less prominent role. When divided according to their nanotech activity categorization (i.e. producer/ disseminator/ commercializer) an interesting differentiation emerges, however, in that knowledge producers and disseminator sites display the strongest tendency to feature the socially relevant terms, whereas the technology producers tend to be largely silent on these matters.

Overall then this analysis has revealed that despite the calls by government and scientists for a greater social responsibility to be displayed in communicating and disseminating the value of nanotechnology, its primary producers are failing to promote this wider public agenda, at least in the online environment. In this sense, it would seem that the organizations involved have not learned any obvious lessons from the GM foods debacle and instead are ‘reverting to type’ in pursuing a narrower self-interested agenda focused on technical advancement and commercial gain rather than broader educational aspirations. While it could of course be argued that this deficit is a reflection of limited investment by nanotech companies in their websites overall, we would argue against this on two main grounds. First, although websites themselves can be expensive to design, once established, adding hyperlinks and meta-tags is essentially ‘cost-free’. The number and nature of a site’s hyperlinks is therefore more likely to be dependent on the authors’ interest in such practices rather than the resources available. Second, by 2007 (when the sites were studied) the idea of a website as an important public face for an organization, particularly a commercial one would have been fairly widely accepted. Given its relative cheapness as a promotional medium and the high likelihood that the consumers of their products would be online then one might even expect nanotech producers to be particularly adept in their use of the medium.

If we interpret the category of producers more widely to include knowledge production, then evidence of a more socially-oriented debate does emerge. The isolated yet prominent position assumed by Foresight in the network reveals that despite the heavy bias of the nanotech industry toward technical presentation of the issues, a narrow yet authoritative space is granted to discussion of the social aspects. The Foresight Nanotech Institute, established in the mid-1980s as a non-profit organization, was one of the first bodies to raise discussion about the benefits and risks of the technology. It has remained one of the most respected voices at the forefront of the public education mission surrounding nanotechnology’s development. In addition, there is some effort by producers to link to the academic community and blogosphere, where more socially orientated discussion of the technology is taking place. Thus, while the social side of the debate may not occupy much room in the network we have uncovered here, the debate is not entirely avoided and certain voices within it are accorded a position of some influence and significance.

Given the Internet’s increasing relevance for day-to-day communication, it is clearly an important medium for those seeking to raise societal awareness on key issues and engage in a program of public education. Websites, e-newsletters and blogs all offer ways for businesses and organizations to communicate directly with consumers and voters, to respond quickly to opponents, and to proactively influence wider media agendas (since mainstream journalists increasingly rely on web sources). Indeed, the Internet and particularly the new generation of Web 2.0 user-driven software offer new ways for citizen-groups to coordinate and campaign both for and against established brands and corporations. As such, the pro-active deployment of online communication tools by nanotechnology companies to convey news and information about their products represents an important route for reaching key opinion formers, both within the media and the wider public. The evidence of our study suggests that for the most part, the major stakeholders involved in nanotech's research and development have not as yet risen to this challenge. Both in terms of the type of information they offer online and the groups they associate with, the nanotechnology industry appear to have adopted a largely self-referencing approach, carving out an online space or niche that would be of interest mainly to specialists in the field. Of course, it may be that the offline communication efforts of nanotech producers demonstrate a stronger engagement with the debate, and this is an area for future work to explore. However, at least on the basis of evidence presented here it does appear that these companies are not seeking to fully exploit the range of opportunities open to them to increase public knowledge on nanotechnology. Given the increasing levels of public and private investment in nanotechnology the question of whether such silence can and should be sustained is one that governments need to consider. As was noted earlier in the paper the regulatory regime surrounding nanotechnology has not been particularly extensive. Keller, who was cited in support of this viewpoint, however also goes on to argue that "a main task for those introducing new technology is building public trust in the safety of the technologies and the integrity of those introducing it" (5). If the industry is failing to deliver on this public mission then stronger directives concerning their communication on the issues may be necessary for engineering this wider societal confidence.

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Table 1: Companies comprising the Merrill Lynch Nanotechnology Index, March 2007

Company Name	Symbol	URL	% Weighting	Speciality
Biosante Pharmaceuticals	BPA	http://www.biosantepharma.com/	5.09%	Nanobio
Kopin Corp	KOPN	http://www.kopin.com/	4.89%	Semis
Skyepharma Plc Ads	SKYE	http://www.skyepharma.com/	4.88%	Nanobio
Cabot Corp	CBT	http://www.cabot-corp.com/	4.66%	Materials
Amcol Intl	ACO	http://www.amcolinc.com/	4.62%	Materials
MTS Systems	MTSC	http://www.mts.com/	4.56%	Instrumentation
Veeco Instruments	VECO	http://www.veeco.com/	4.46%	Instrumentation
Accelrys Inc	ACCL	http://www.accelrys.com/	4.43%	Instrumentation
Flamel Technologies Ads	FLML	http://www.flamel.com/	4.38%	Nanobio
FEI Co	FEIC	http://www.fei.com/	4.28%	Instrumentation
Immunicon Corp	IMMC	http://www.immunicon.com/	4.18%	Nanobio
Headwaters Inc.	HW	http://www.headwaters.com/	4.10%	Energy
Nanophase Technologies	NANX	http://www.nanophase.com/	3.85%	Materials
Altair Nanotechnologies	ALTI	http://www.altairnano.com/	3.83%	Materials
Ultratech Inc	UTEK	http://www.ultratech.com/	3.83%	Instrumentation
Symyx Technologies	SMMX	http://www.symyx.com/	3.81%	Instrumentation
Arrowhead Research	ARWR	http://www.arrowres.com/	3.80%	Multi
Westaim Corp	WEDX	http://www.westaim.com/	3.77%	Nanobio
Novavax Inc	NVAX	http://www.novavax.com/	3.53%	Nanobio
Harris & Harris Group Inc	TINY	http://www.tinytechvc.com/	3.51%	Venture Capital
pSivida Ltd. (ADS)	PSDV	http://www.psivida.com/	3.50%	Nanobio
Nanogen Inc	NGEN	http://www.nanogen.com/	3.47%	Nanobio
Acacia Research-Combimatrix	CBMX	http://www.acaciaresearch.com/	3.38%	Multi
NVE Corp	NVEC	http://www.nve.com/	2.61%	Semis
Lumera Corp	LMRA	http://www.lumera.com/	2.60%	Semis

Table 2: Classification of nanotechnology-related web sites

Country	*count*	*generic TLD*	*count*
Australia	3	biz	1
Austria	1	com	99
Belgium	1	edu	10
Canada	5	gov	7
China	2	mil	1
Denmark	1	net	12
Egypt	1	org	29
Europe	1	unknown	20
Finland	1	total	179
France	6		
Germany	11	***Type***	***count***
India	1	producer - tech co	63
Israel	1	producer - knowledge	31
Italy	3	dissem. - academic	17
Japan	4	dissem. - basic/blog	13
Netherlands	1	dissem. - industry	16
New Zealand	1	commerc. - consortia	10
Romania	1	commerc. - infosites	29
Russian Federation	3	Total	179
Spain	1		
Switzerland	3	***Focus***	***count***
Taiwan	1	Social	13
United Kingdom	13	Technical	166
United States	109	Total	179
unknown	4		
total	179		

Table 3: Network measures by social/technical orientation of site

	N	*indegree*	*outdegree*	*hits authority*	*hits hub*	*betweenness*
Social	13	10.3	14.6	0.067	0.089	272.0
Technical	161	7.3	7.0	0.048	0.043	166.9
total	174	7.5	7.5	0.049	0.047	174.7
(www.foresight.org ommitted)						
Social	12	6.8	10.6	0.051	0.076	55.5
Technical	161	7.0	6.7	0.049	0.045	166.9
total	173	7.0	7.0	0.049	0.047	159.1

Note: 5 sites could not be accessed by the web crawler and hence were excluded from this table.

Table 4: Network measures by site type

	N	*Indegree*	*Outdegree*	*hits authority*	*hits hub*	*betweenness*
producer - tech co	58	3.7	1.3	0.024	0.014	27.7
producer - knowledge	31	8.5	7.9	0.057	0.052	218.2

dissem. - academic	17	8.6	8.3	0.054	0.055	131.1
dissem. - basic/blog	13	5.3	17.0	0.038	0.120	92.7
dissem. - industry	16	9.9	8.4	0.065	0.045	257.7
commerc. - consortia	10	3.9	21.2	0.027	0.115	240.2
commerc. - infosites	29	14.5	9.7	0.090	0.047	416.2
total	174	7.5	7.5	0.049	0.047	174.7

Note: 5 of tech producer sites were not included from Table 2 due to inability to crawl outbound links.

Table 5: Top-10 sites (sorted on indegree, and HITS hub score)

Sorted on indegree

URL	*Country*	*Type*	*Focus*	*indeg*	*outdeg*	*hits_hub*	*hits_auth*	*betweenness*
http://www.smalltimes.com/	US	commerc. - infosites	technical	64	8	0.011	0.311	1808.5
http://www.nanovip.com/	US	commerc. - infosites	technical	52	46	0.205	0.288	3635.4
http://www.foresight.org/	US	producer - knowledge	social	48	56	0.245	0.261	2869.2
http://www.nano.gov/	US	producer - knowledge	technical	48	33	0.156	0.254	2400.2
http://www.nanotechweb.org/	UK	commerc. - infosites	technical	45	0	0.000	0.244	0.0
http://www.nsti.org/	US	dissem. - industry	technical	44	51	0.196	0.231	3784.7
http://www.nano.org.uk/	UK	commerc. - infosites	technical	42	19	0.084	0.246	2342.8
http://www.azonano.com/	Australia	commerc. - infosites	technical	32	11	0.027	0.214	510.8
http://www.nanoforum.org/	Germany	dissem. - academic	technical	32	6	0.022	0.152	716.2
http://www.nanotechnology.com/	US	commerc. - infosites	technical	32	2	0.007	0.207	314.4

Sorted on HITS hub score

URL	*Country*	*Type*	*Focus*	*indeg*	*outdeg*	*hits_hub*	*hits_auth*	*betweenness*
http://www.nstc.in/	India	commerc. - consortia	technical	3	75	0.266	0.017	1582.5
http://www.foresight.org/	US	producer - knowledge	social	48	56	0.245	0.261	2869.2
http://www.nanotec.it/	Italy	commerc. - consortia	technical	3	38	0.212	0.023	212.6
http://www.nanobot.blogspot.com/	US	dissem. - basic/blog	technical	19	34	0.207	0.131	627.9
http://www.nanovip.com/	US	commerc. - infosites	technical	52	46	0.205	0.288	3635.4
http://www.thenanotechnologygroup.org/	US	dissem. - academic	technical	11	35	0.203	0.093	245.3
http://www.nsti.org/	US	dissem. - industry	technical	44	51	0.196	0.231	3784.7
http://www.nanotechbuzz.com/	US	dissem. - basic/blog	technical	6	28	0.193	0.040	54.8
http://nanotechnologie.startpagina.nl/	Netherlands	dissem. - industry	technical	0	30	0.180	0.000	0.0
http://www.venetonanotech.it/	Italy	commerc. - consortia	technical	1	23	0.176	0.010	3.2

Table 6: Top-10 sites (sorted on HITS authority score, beweenness centrality)

Sorted on HITS authority score

URL	*Country*	*Type*	*Focus*	*indeg*	*outdeg*	*hits_hub*	*hits_auth*	*betweenness*
http://www.smalltimes.com/	US	commerc. - infosites	technical	64	8	0.011	0.311	1808.5
http://www.nanovip.com/	US	commerc. - infosites	technical	52	46	0.205	0.288	3635.4
http://www.foresight.org/	US	producer - knowledge	social	48	56	0.245	0.261	2869.2
http://www.nano.gov/	US	producer - knowledge	technical	48	33	0.156	0.254	2400.2
http://www.nano.org.uk/	UK	commerc. - infosites	technical	42	19	0.084	0.246	2342.8
http://www.nanotechweb.org/	UK	commerc. - infosites	technical	45	0	0.000	0.244	0.0
http://www.nsti.org/	US	dissem. - industry	technical	44	51	0.196	0.231	3784.7
http://www.azonano.com/	Australia	commerc. - infosites	technical	32	11	0.027	0.214	510.8
http://www.nanotechnology.com/	US	commerc. - infosites	technical	32	2	0.007	0.207	314.4
http://www.crnano.org/	US	dissem. - academic	social	24	25	0.164	0.173	234.5

Sorted on betweenness centrality

URL	*Country*	*Type*	*Focus*	*indeg*	*outdeg*	*hits_hub*	*hits_auth*	*betweenness*
http://www.nsti.org/	US	dissem. - industry	technical	44	51	0.196	0.231	3784.7
http://www.nanovip.com/	US	commerc. - infosites	technical	52	46	0.205	0.288	3635.4
http://www.foresight.org/	US	producer - knowledge	social	48	56	0.245	0.261	2869.2
http://www.nano.gov/	US	producer - knowledge	technical	48	33	0.156	0.254	2400.2
http://www.nano.org.uk/	UK	commerc. - infosites	technical	42	19	0.084	0.246	2342.8
http://www.nanowerk.com/	US	commerc. - infosites	technical	22	42	0.151	0.139	2183.8
http://www.smalltimes.com/	US	commerc. - infosites	technical	64	8	0.011	0.311	1808.5
http://www.nstc.in/	India	commerc. - consortia	technical	3	75	0.266	0.017	1582.5
http://www.fei.com/	US	producer - tech co	technical	4	12	0.099	0.013	1163.0
http://www.nanoforum.org/	Germany	dissem. - academic	technical	32	6	0.022	0.152	716.2

Table 7. Keywords identified

Business	Innovation [innovate, innovation, innovator, innovative]
Capital	Investing [invest, investing, investment, investor]
Citizen	Opportunity
Collaborate	Policy [policy, policymakers]
Debate	Politics
Dialogue	Public
Discussion	Responsibility [responsible, responsibility, responsibly]
Education	Risk
Environment	Science
Ethics	Society [social, societal, society]
Health	Threat

Table 8. Keywords by type of website producers

	Overall	**Production**		**Commercialization**		**Dissemination**		
		Technology	*Knowledge*	*Consortia*	*Infosites*	*Basic*	*Academic*	*Industry*
	%	*%*	*%*	*%*	*%*	*%*	*%*	*%*
Industry	27	16	26	10	38	54	35	38
Science	25	17	32	10	38	38	29	12
Business	18	11	13		31	23	18	44
Environment	17	6	23	10	21	38	29	19
Health	16	5	23	10	17	46	29	13
Invest	16	3	3	30	31	46	12	38
Innovation	15	13	13		17	31	18	13
Discussion	15	2	16	10	14	46	29	31
News	13	3	16	10	28	38	12	6
Opportunity	13	8	6	10	17	8	29	31
Safety	12	3	16	10	17	31	24	6
Future	11	2	13		14	38	24	6
Society	11		23	10	3	38	24	13
Education	10		13	10	14	31	12	19
Risk	9		13		14	54	12	
Collaboration	9	3	3	20	17	15	6	19
Policy	7		10		7	23	24	6
Ethics	6		19			23	6	
Responsibility	5	2	3		14	8	12	
Debate	5		6			31	6	13
Politics	3		6			15	6	
Capital	3				7	15		13
Threat	3		3			23	12	
Dialogue	2		6			8	6	
N = 179		*63*	*31*	*10*	*29*	*13*	*17*	*16*

Table 9. Dimensions of nanotechnology discourse

	Dimension of discourse		
	1 – industrial / proactive	2 – science / education	3 – social / critical
Industry	.408	**1.109**	**.673**
Science	**-.435**	**1.019**	**-.644**
Education	.022	**.324**	**-.318**
Environment	**-.697**	.240	**.392**
Business	**.972**	.222	-.299
Policy	-.121	.162	.141
Discussion	**-.715**	.095	-.228
Future	-.235	.068	**-.406**
Responsibility	.026	.034	.087
Capital	.250	.022	.010
Opportunity	**.636**	-.019	**.490**
Safety	**-.345**	-.048	**.454**
Dialogue	.011	-.101	-.063
Collaboration	.421	-.107	**-.300**
Debate	.113	-.138	.134
Risk	**-.360**	-.184	.069
Politics	.063	-.209	-.013
Innovation	.162	-.210	**-.789**
News	.016	-.223	**.660**
Threat	-.004	**-.262**	.043
Ethics	-.055	**-.380**	-.134
Society	**-.345**	**-.446**	-.262
Invest	**.746**	**-.483**	-.051
Health	**-.536**	**-.486**	**.354**

Notes
Multi-dimensional scaling space coordinates.
Proxscal algorithm with squared Euclidean distances.
Bold denoted most significant keywords.
Three dimensions chosen, Stress = 0.027.
Table ordered by the Dimension 2, decreasing values.

Table 10. Relation between discourse dimensions and producers' focus

Scales	*Scale min, max, mean, SD*	*Focus*	*N*	*Mean*	*SD*	*Sig.*
Proactive / industry	-3.02 3.01 .003 1.00	Technical	166	.09	.94	***
		Social	13	-1.10	1.20	
Constructive / education	-1.89 2.46 .362 .79	Technical	166	.40	.77	*
		Social	13	-.14	.95	
Critical / social	-2.19 3.09 .034 .70	Technical	166	.02	.66	
		Social	13	.26	1.12	

Notes
Results of independent samples t-test
Test variables: three dimensional scales
Grouping variable: website focus

Table 11. Correlations between discourse dimensions and network measures

	Hits hub	Hits authority	Proactive / industry	Constructive / education	Critical / social
Hits hub	1	.248 (**)	-.096	-.004	.004
Hits authority		1	-.033	.214 (**)	.068
Proactive / industry			1	.059	-.017
Constructive / education				1	-.051
Critical / social					1

Notes
N = 179
Pearson's correlation coefficients
** = correlation is significant at the 0.01 level (2-tailed).

Figure 1. 174 seed sites – nanotechnology focus

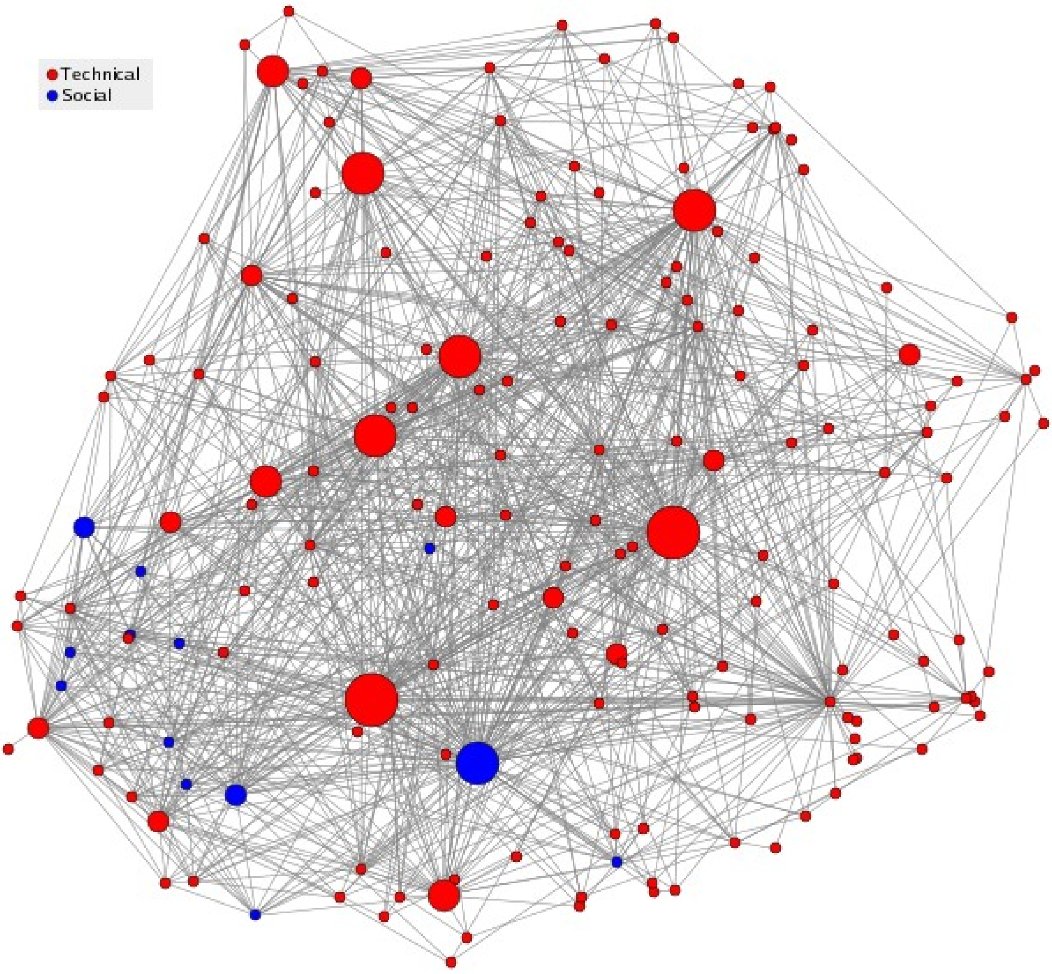
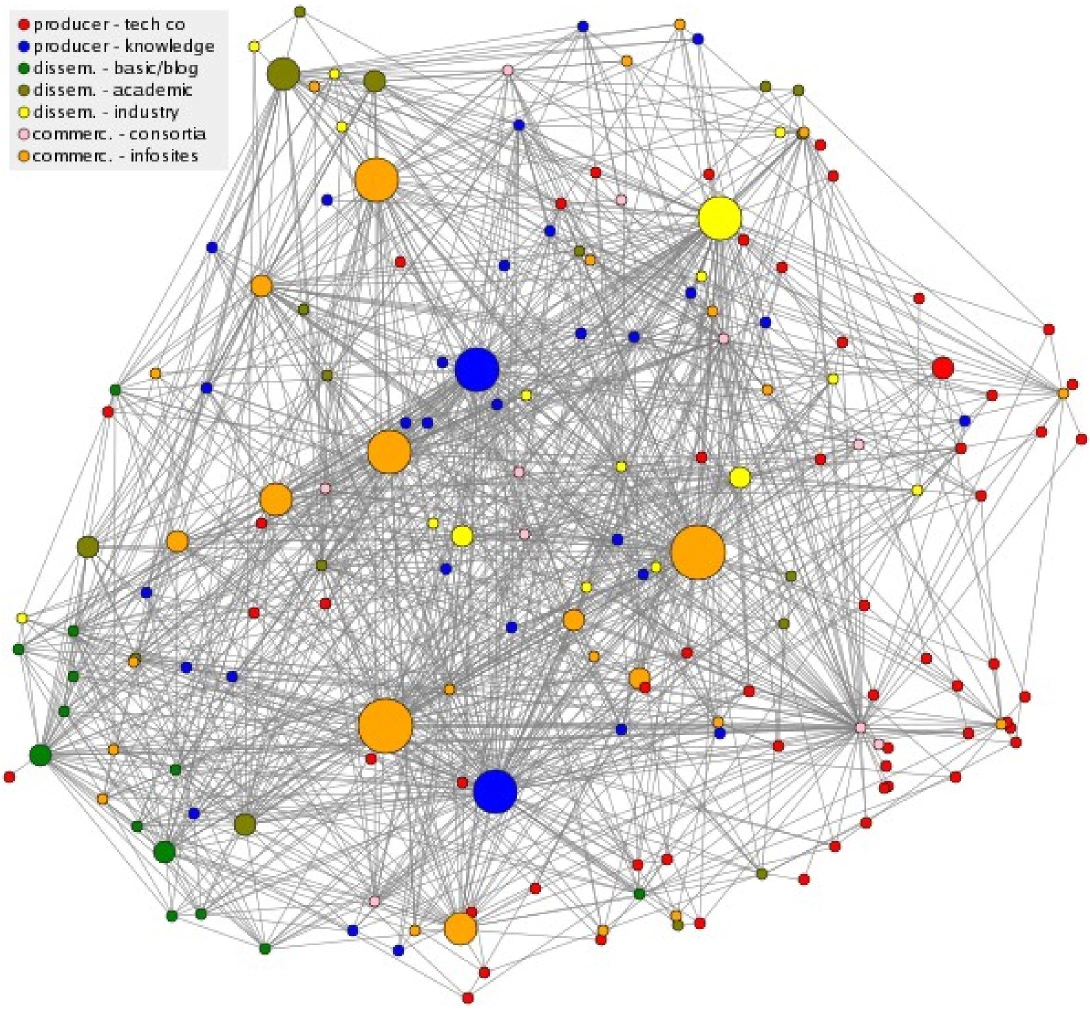


Figure 1. 174 seed sites – site type



[1] The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

[2] See 'Alert over the march of 'grey goo' in nanotechnology foods' by S. Poulter, 02/01/08 *MailOnline* Available at < http://www.dailymail.co.uk/sciencetech/article-505561/Alert-march-grey-goo-nanotechnology-Frankenfoods.html>; 'The Gray Goo Problem' by L. Osborne, 14/12/03 *The New York Times Magazine* Available at http://www.nytimes.com/2003/12/14/magazine/14GRAY.html

[3] Earlier work by Bainbridge (2002) had indicated higher levels of knowledge among respondents to a series of nanotech-related questions. However, the survey instrument, Survey2001 was a web-based survey run through National Geographic's website using self-selected respondents worldwide, and has been subsequently questioned in regard to how representative results are of the general publics of these nations (Waldron et al., 2006).

[4] See http://voson.anu.edu.au and particularly Ackland and Gibson (2004), Ackland et al. (2006) and O'Neil and Ackland (2006) for more details on the methods of data collection that are facilitated by the VOSON System.

[5] http://www.amex.com/?href=/othProd/prodInf/OpPiIndComp.jsp?Product_Symbol=NNZ

[6] Of the 179 sites, 120 were subject to joint coding by Ackland and one other author. The 59 excluded sites contained the original 25 technology companies plus a further obvious 29 technology companies that were coded by Ackland (these were set to 'producer-tech' and 'technical' in orientation). A further five sites were foreign language and were coded by Ackland using translators (where available) and/or web translation services. Of the 120 sites left, category 1) (site activity) codes matched in 77% of cases and category 2) orientation matched in 97% of cases. Face-to-face consultation resolved any conflicts.

[7] With a force-directed graph, nodes (in this case, websites) are randomly positioned and forces are assigned as if the nodes are electrostatic charges (repelling each other) and edges (in this case, hyperlinks) are springs (pulling connected nodes together). The algorithm shifts the position of nodes in an attempt to minimize the energy of the system, sometimes revealing clusters of nodes that are more inter-connected.

[8] Note that all the network measures were calculated using only information on hyperlinks between the 174 sites. Hence, indegree for a given site refers to the number of hyperlinks pointing to that site originating from other sites within the set of 174 sites (*not* the number of inbound hyperlinks from the rest of the web).

[9] Thus, there is a mutually reinforcing relationship between authorities and hubs: a good hub points to many good authorities, and a good authority is pointed to by many good hubs. To calculate the HITS measures, each website p is associated with with an authority weight x(p) and a hub weight y(p), which are initialised to 1. In a single iteration of HITS x(p) is replaced by the sum of the y's of all websites pointing to p, and y(p) is replaced by the sum of the x's that page p points to. After each iteration, the x's and y's are normalised and convergence is generally achieved after less than 10 iterations.

[10] The betweenness centrality $C_B(v)$ for vertex *v* is: $C_B(v) = \sum_{s \neq v \neq t \in V(G)} \frac{\sigma_{st}(v)}{\sigma_{st}}$, where $\sigma_{st}(v)$ is the number of shortest paths from node *s* to *t* that pass through *v*, and σ_{st} is the total number of shortest paths from node *s* to *t*. Betweenness is sometimes normalised to sum to 1 over all nodes.

[11] By focusing on the mention of keywords rather than the direction or sentiment (positive/negative) associated with their use we adopt a valence-based approach to our coding. Such an approach is not un-common in social science literature (Stokes, 1963, 1992; Clark, 2009) and considered appropriate here in that although nanotechnology elicits strong pro and anti-positions, the terms used within the debate are more likely to be unipolar in nature, i.e. most people would either support or oppose such as safety,

ethics, security, risk and environment. Our expectations can be seen to be validated by the results reported in table 8 which cross-tabulates the occurrence of a key word by site types and shows a much lower incidence of nanotech producer sites making any reference to the socially relevant terms.

[12] Dimensional scales values for discrete websites were obtained by multiplying keywords occurrence by dimensional coordinates. Scales thus obtained had no significant correlations (Table 11).