Nanotechnology as Ideology: Towards a Critical Theory of 'Converging Technologies'

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The present paper contributes to a growing body of philosophical, sociological, and historical analyses of recent nanoscale science and technology. Through a close examination of the origins of contemporary nanotech efforts, their ambitions, and strategic uses, it also aims to provide the basis for a critical theory of emerging technologies more generally, in particular in relation to their alleged convergence in terms of goals and outcomes. The emergence, allure, and implications of nanotechnology, it is argued, can only be fully appreciated if one looks beyond its immediate technical and scientific payoffs to its infrastructural and ideological aspects. While nanotechnology aims to reshape the world 'atom by atom', its most tangible result so far has been the profound effect it has had on the organization of science-at-large, not least as the result of a thorough reshaping of the 'soft' funding infrastructure that places significant constraints on the pursuit of long-term scientific research programmes. The paper concludes by noting a persistent, and perhaps deepening, gap between the utopian visions of some of nanotechnology's most vocal proponents and the realities of contemporary nanotechnological practice, which continue to be marked by global inequities.

Introduction

Nanoscale science and technology has captured the public and scientific imagination like few techno-scientific projects before. From its speculative beginnings as an envisioned 'science of the very small' it quickly developed into a multi-billion dollar enterprise, reshaping science policy and traditional scientific disciplines. The present paper analyses the extent and character to which nanotechnology has led to a reorganization of science as a collective endeavour, as well as the ideological assumptions underlying its success. In doing so, this paper contributes to a growing body of philosophical, sociological, and historical analyses of nanoscience. In particular, it attempts to synthesize perspectives from currently disconnected literatures into a coherent critical theory of nanotechnology and related emerging technologies.

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The rest of this paper is organized into five sections. The section 'Imaginary ancestry vs real history' contrasts the imaginary ancestry of nanotechnology, which has become part of its self-image, with the events and policy shifts leading up to US President Bill Clinton's proposal, in the year 2000, of a National Nanotechnology Initiative. The section 'A nanotechnological infrastructure' argues that the implications of nanoscale science and technology, and corresponding funding efforts, can only be fully appreciated if one recognizes its infrastructural ambition. Nanotechnology aims to reshape the world 'atom by atom', yet its implementation through science policy also has profound effects on the organization of science-at-large. The section 'Does nanotech have politics?' extends this argument by analyzing the political dimension of recent nanotech efforts; drawing on work by Langdon Winner and Jürgen Habermas, it attempts to give a tentative answer to the programmatic question posed in the section title. The section 'Dreams of "convergence…"' broadens the perspective further, by discussing the ideological underpinnings of nanotechnology and connecting it with a cognate discourse on 'converging technologies'. With its emphasis on the transformational power of 'bottom-up' processes such as self-assembly and self-replication, nanotechnology lends indirect support to ideas of 'spontaneous order' that are characteristic of neoliberal discourse in the social and political realm; a strong dose of technological determinism further adds to the air of inevitability that surrounds the utopian visions put forward by some of nanotechnology's most vocal proponents.

Imaginary Ancestry vs Real History

Contemporary nanotechnology appears to boast impeccable credentials: As common lore has it, Richard Feynman pointed the way in a 1959 lecture given at the annual meeting of the American Physical Society at Caltech (see Feynman, 1960). In the lecture, programmatically entitled 'There's Plenty of Room at the Bottom', Feynman muses about what it would take to carry miniaturization all the way through to the atomic level, and speculates about '[w]hat would happen if we could arrange the atoms one by one the way we want them' (Feynman, 1960: 34). Possible applications he envisaged include massively increased storage and computing power of microcomputers as well as biomedical uses, ranging from a 'mechanical surgeon inside the blood vessel' to small machines that 'might be permanently incorporated in the body to assist some inadequately-functioning organ' (Feynman, 1960: 30). Towards the end of his lecture, Feynman issued a technological challenge to students, promising a reward for 'the first guy who can take the information on the page of a book and put it on an area 1/25,000 smaller in linear scale in such manner that it can be read by an electron microscope', and adding that he did 'not expect that such prizes will have to wait very long for claimants' (Feynman, 1960: 36).

On the face of it, Feynman's lecture has all the hallmarks of a 'founding moment' in the history of science. Many of the principles and goals of nanotechnology—such as miniaturization and convergence of physical, chemical, and biological processes at the molecular level—are already explicit in Feynman's lecture, and several of his predictions indicate a great deal of foresight. Feynman's lecture spells out—in a clear yet non-technical language that has an undeniable programmatic ring to it—an agenda for a future 'science of the very small'; the fact that it ends by setting a concrete technological challenge—complete with an economic incentive in the form of a cash reward—along with the evocative imagery throughout the text (think 'mechanical surgeon inside the blood vessel') contributes to the sense that the envisaged nano-world is already almost within our grasp.

The only minor flaw of this alleged ancestry of contemporary nanotechnology is that it is largely imaginary. Nowhere in his lecture does Feynman use the 'nano' prefix, preferring instead to use purely qualitative designations such as 'very small' or 'very little'. The most well-developed examples in the text concern the development of *micro*-electronics, such as circuits 'a few thousand angstroms across' and 'little coils and condensers (or their solid state analogs) 1,000 or 10,000 angstroms in a circuit' (Feynman, 1960: 34). While Feynman's lecture makes a strong case for miniaturization, and the technological possibilities it affords, its focus is by no means exclusively on length scales in the nano-realm. Several commentators have pointed out that, although Feynman's ideas were briefly taken up by the popular press, for example in *Saturday Review*, *Popular Science* and *Life*, his published lecture had virtually no impact on scientific development. This only changed in the 1990s, following the reprint of an excerpt from Feynman's text in a special issue of *Science* that was already devoted to the—independently emerging—new discipline of 'nanotechnology' (see Toumey, 2005). Feynman's idea of a 'mechanical surgeon' inside the blood stream is strongly reminiscent of earlier science fiction stories such as Robert Heinlein's *Waldo* (1942), and it has been argued that it was not Feynman's considerations that were of inspirational value to the emergence of nanotechnology, but pop-cultural phenomena such as science fiction and the cyberpunk movement of the 1980s.[1]

US President Bill Clinton invoked the Feynman connection during a speech at Caltech on 21 January 2000, in which he unveiled the United States' National Nanotechnology Initiative (NNI). As two White House advocates for the NNI recall, efforts to establish formal interagency initiatives in nanoscale science and engineering 'began in earnest in the fall of 1998' (Lane and Kalil, 2007: 81). An Interagency Working Group on Nanoscience, Engineering and Technology (IWGN) under the auspices of the National Science and Technology Council (NSTC) was set up, and its NNI proposal was recommended by the President's Council of Advisors on Science and Technology (PCAST) for inclusion in the fiscal year 2001. Clinton took to the initiative quickly, reportedly including a reference to it in his 2000 State of the Union address, against the advice of his speech writers, and regarding the NNI as a 'centerpiece of a much broader research initiative to address the growing imbalance in federal funding for biomedical research and the physical sciences and engineering' (Lane and Kalil, 2007: 82). Through the re-designation of existing budget items, as well as the injection of new funds, US $422 million were provided by the US Congress for nanoscale science and engineering in the fiscal year 2001; 10 years later, the amount had more than quadrupled to US $1.8 billion in FY2011 (see NNI, 2010a).

One aspect that is not typically discussed in official NNI documentation, and is also omitted by Lane and Kalil in their afore-mentioned paper (2007), concerns the role of international rivalry in the initial formation of national nanotechnology policy. While the NSTC was established as a government institution by Executive Order in 1993, several of the early meetings of what was to become the IWGN were held under the auspices of the World Technology Evaluation Center (WTEC), formerly a division of Loyola College, which was later spun off as an independent NGO. In a previous incarnation, the WTEC was known as the Japanese Technology Evaluation Center (JTEC) and regarded it as its mission to monitor developments in Japanese science and technology, with a special emphasis on micro-electromechanical engineering. A report in 1994 noted that Japan, thanks to a decade-long funding programme, should be regarded the leader in 'miniaturization of more traditional (nonlithographic) machining processes', for which there was 'no comparable U.S. effort' (JTEC, 1994). While the rhetoric of these (and subsequent) reports was moderate, their implications were clear: if the US was to keep up with international scientific developments, it would have to restructure its haphazard funding system in order to make it as systematic and comprehensive as that of its competitors, Japan and Europe. Japanese scientists had already synthesized nanotubes in 1991, the same year MITI had pledged the equivalent of US $225 million for future research in nanotechnological applications in the microelectronics sector. (See Crawford, 1991; McCray, 2005.) The apparent head start of other major industrialized nations in the race towards nanotechnology clearly impressed on US policymakers the urgency of a unified and comprehensive response.

Ironically, the alleged strategic importance of nanotechnology seems to have played little role in the pre-NNI funding efforts of either Japan or Europe; the US 'response' caught them by surprise and, in a classic case of 'keeping up with the Joneses', triggered a massive international re-organization of science funding. An interesting example is the response of the German Federal Government, which Schummer (2009: 19) has chronicled as follows: In January 2002, the Federal Ministry of Education and Research (BMBF) published a survey of research spending by the Federal Government. The report lists 'nanotechnology' as an area within 'materials science', and gives an estimate of 72 million Euros for the total amount of federal received between 1997 and 2005. Only a few months later, the BMBF published a report 'Nanotechnology in Germany', which claims that between 1998 and 2004, a total of 350 million Euros was spent on nanotechnology research. Noting that in the current fiscal year 88.5 million Euros had been earmarked for nanotech purposes, the report concludes that federal funding for nanotechnology 'has risen by 221% since 1998'.[2] As in the US case of the mobilization of funds for the NNI, an important factor in the growth of nanotechnology was the re-designation of established fields of research as 'nano-science', thus bringing them within the purview of the new nanotech initiatives—sometimes, as in the German case of the miraculous multiplication of nanotech funds, even retrospectively.

Whereas popular portrayals of nanotechnology tend to emphasize the novelty of the new technologies, along with their transformative and revolutionary potential, many researchers and policymakers acknowledge the heterogeneity of nanoscale science and technology, including the fact that much of what is now called nanoscience has been carried out for decades under such labels as 'applied chemistry', 'surface physics', 'macromolecular physics', 'supramolecular chemistry', and 'materials science'. Anderson et al. (2009) recently conducted a series of interviews and surveys with scientists and policymakers on the prospects and risks, as well as the origins, of nanotechnology. Typical statements include the following from a research associate in the private sector:

> In my field we have been operating at the nanoscale for many years, if not decades, so many of the problems and benefits are well known. (Anderson et al., 2009: 139)

Similarly, an economic policy manager for a regional development agency remarks:

> I think [nanotechnology is] perceived to be something new and novel and different and, actually, in many cases, it's just that the measurement and capability to measure to that scale is now available, so we can measure to that scale and smaller and so we've recognised it and we've given it a classification. (Anderson et al., 2009: 140)

As far as *actual* scientific knowledge is concerned, it might seem plausible, then, to suspect that nanotechnology over the past decade has added little that could not have been achieved from within the framework of one of the more traditional subdisciplines of applied chemistry and physics. However, while it is true that 'nano experiments often yield *knowledge* that is siphoned into the experimenter's home discipline', it has also been noted that, from a nanoscience perspective, the value of such experiments often resides in 'a "proof of concept" for some process or mechanism that—in the future—can be integrated into a more complex nanomachine' (Mody, 2004: 109). As I shall argue in the section 'Dreams of 'convergence'', it is important to understand current nanoscience as a promissory enterprise, that is: a science of things to come.

As mentioned earlier, the US's NNI was partly conceived as a response to the disparities in research funding between the biomedical sciences and the physical and engineering sciences. The latter had enjoyed pride of place throughout much of the Cold War, thanks to the union that had been forged, in the form of post-World War II 'Big Science' (see Galison, 1992), between basic science and defence research. With the fall of Communism and the collapse of the Soviet Union, much of the ideological rationale for basic research in the physical sciences had evaporated;

research institutions, especially those with an affinity to nuclear research, were thus keen to identify new areas that could plausibly be regarded as 'of strategic interest'. Additionally, 'the end of the Cold War signaled to [US] policy makers that the next arena of conflict would be in the global marketplace in the form of increased economic competition from European and Asian countries' (McCray, 2005: 186). Both tendencies were present in pre-NNI political discourse, including in testimony given to the US House of Representatives' Committee on Science in its review of federal funding for nanotechnology. During the hearings, Nobel Prize winner Richard E. Smalley pandered to national economic self-interest when he spoke of 'a growing sense in the scientific and technical community' that 'we are about to enter a golden new era'; another witness explicitly compared commitment to nanotechnology to John F. Kennedy's declaration to put a man on the moon.[3] The promises and prospects of nanotechnology thus came to fill a political-ideological vacuum that had developed since the disappearance of Communism as a global threat; nanotechnology, with its perceived economic applications and its vision of easily deployable, possibly self-organizing systems, seemed eminently suitable for an age in which conflicts would be more localized and competitions between countries, as US lawmaker Newt Gingrich put it, 'less military and largely economic'.[4] Feynman's innocent musings, some 40 years earlier, about how to make computers smaller and what it would take to build a toy car 1/4000th the size of a real one, were seized upon as an imaginary ancestor that could lend authority and credibility to the pursuit of a future 'nanocosm'.

A Nanotechnological Infrastructure

As has already been mentioned, it is difficult to ascertain which scientific innovations and results over the past few years are genuinely 'nanoscientific' in character and which would have developed independently of major initiatives such as the NNI. This is only to be expected, given that the new field of 'nanoscience' is the joint result of, on the one hand, a re-branding exercise of existing research programmes within a more traditional disciplinary setting and, on the other hand, genuinely new institutional structures and research projects. Among the most frequently cited nanotechnology applications are the antimicrobial use of silver nanoparticles, drug delivery applications and various kinds of coatings with advanced optical, mechanical and rheological properties. However, many of these applications are still fairly narrowly confined to specific domains, and more ambitious projects—such as the design of self-replicating micro-machines or solutions to energy security, global warming, and desalination (all of which are commonly cited in connection with nanotechnology, for example by Lane and Kalil, 2007)—are still in their infancy.

There is no reason to think that scientific progress over the past decade, in the areas now subsumed under the label 'nanoscience' should, on the whole, be any less substantial than in many other areas of science. However, as some critics have pointed out, the move towards nanotechnology—in particular in those instances where it involves 're-branding' of existing research programmes—has, on occasion, led to an erosion of distinctions that previously seemed justified on theoretical grounds. As Schummer (2009: 32) points out, whereas scientists used to make a careful distinction between different kinds of porous materials, with a division by pore size into microporous (< 2nm), mesoporous (2–50nm) and macroporous (> 50nm), now it is common to speak more generally of 'nanoporous' (< 100nm) materials.[5] The transition to 'nanoscience' was driven more by the top-down reorganization of funding efforts than by intra-scientific considerations, such as—on a Kuhnian model—the existence of persistent theoretical anomalies. However, its effects on the character of theoretical knowledge within the various sub-disciplines are not altogether different from more 'bottom-up' shifts in the history of science. In particular, as the reclassification of porous materials suggests, there may well be an element of 'Kuhn loss'[6] involved, that is: an impairment of the ability 'to see the point' in previously entrenched debates, classifications, or theoretical problems.

If nanotechnology, or nanotech research, is seen as having made a lasting contribution to science at large, then this contribution must consist not in scientific breakthroughs and technological innovations *per se*, but in something altogether different. In the remainder of this paper, I wish to argue that the contributions of nanoscience and nanotech research to science-at-large need to be assessed along two dimensions which, for lack of a better terminology, I shall call 'infrastructural' and 'ideological', respectively. I shall have more to say about the ideological aspects of the nanotechnology agenda which, as I argue in the section 'Dreams of "convergence"', are intimately tied to its character as a promissory undertaking. In the present section, I wish to develop the idea that nanotechnology as a research agenda is primarily aimed at a thoroughgoing transformation of the scientific infrastructure, where the latter is here understood as comprising the technological, social, and institutional background structures that scientists, by necessity, rely upon in their daily work.

The infrastructural ambitions of nanotechnology efforts are clearly manifest in the official rhetoric of national research agencies. For example, the Russian Corporation of Nanotechnologies (Rusnano) was established by federal law in 2007 'in order to assist the implementation of state policy in the sphere of nanotechnologies' and to foster 'development of innovation infrastructure' (Rusnano, 2007). The US NNI, in relation to education and workforce needs, calls specifically for the 'full utilization of the NNI infrastructure', which 'includes centers and user facilities support[ing] research on nanomanufacturing and nanoscale characterization, synthesis, simulation and modeling' (NNI, 2010b). In this task, it is aided by the NSF-funded 'National Nanotechnology Infrastructure Network' (NNIN), which describes itself as 'an integrated partnership of fourteen user facilities […] providing unparalleled opportunities for nanoscience and nanotechnology research' (NNIN, 2010). The German Federal Ministry of Education and Research, in its April 2010 presentation of a new 'action plan' concerning nanotechnology, emphasizes the role of a 'supporting infrastructure' consisting of new 'centres of competence' (*Kompetenzzentren*). (See BMBF, 2010.)

References to 'nanotechnology infrastructure' tend to be ambiguous, especially in the context of policy recommendations, which often trade on the subtle conflation of the scientific infrastructure needed to carry out specific research projects (for example, infrastructure in the form of 'highly specialised buildings and equipment'; NNI 2010b), and the beneficial effects such investments are thought to have on infrastructure more broadly (for example, by contributing to an overall 'innovation infrastructure'; Rusnano, 2007). That scientists need access to specialized equipment, materials, workspace, scientific data and a qualified workforce is, of course, trivial. By contrast, my claim that nanotechnology has an 'infrastructural' ambition is meant to go beyond this obvious need for infrastructural support of ongoing and future research. The nanotechnology agenda, I want to suggest, differs from traditional research efforts in that it seeks to transform the scientific infrastructure beyond what is required in order to achieve specific innovation goals. In order to see what this might mean, it is instructive to briefly reflect on the notion of infrastructure more generally, especially in its relation to the social aspects of technology and its history.

In common parlance, 'infrastructure' typically refers to the man-made 'hardware' that underlies systems for the provision of essential goods and services, such as electricity, water, transport, communication and so on. From a technologist's perspective, it might appear, then, that infrastructure is primarily artefactual in character. However, social historians of technology have pointed out that '[n]ot only hardware but organization, socially communicated background knowledge, general acceptance and reliance, and near-ubiquitous accessibility are required for a system to be an infrastructure' (Edwards, 2004: 188). When infrastructure is functioning properly—as it does in most developed countries, to a remarkable degree of reliability—it blends seamlessly with people's everyday lives, pervading both the workplace and, increasingly, people's personal space. It is in this sense that one can speak of the *socio-technical* character of infrastructure, as 'binding hardware and internal social organization to wider social structure' (Edwards, 2004: 190). At the same time that infrastructures are rendered unnoticeable by their very pervasiveness and unobtrusive availability, they are conceptualized as being separate from society at large. For example, as Paul Edwards points out, 'the causes of infrastructural breakdowns such as power blackouts or telephone outages are nearly always reported either as "human error," which codes the problem as individual and allows the assignment of blame, or as technological failure' (Edwards, 2004). One might go even further and argue that, since technological failures are typically regarded as remediable by technological means, the 'bottom layer' of infrastructure—their material hardware, and the basic technological codes governing their proper deployment—are rendered *ontologically immune* to criticism.

To what extent can the ambitions of nanotechnology be called 'infrastructural', in the sense of 'infrastructure' outlined in the preceding paragraph? While the function of infrastructure is generally identified with the provision of basic services, what counts as 'basic' of course changes over time. Take the example of internet access. Only a few years ago, a fast internet connection was regarded, if not as a luxury, then certainly as something 'non-basic'. Today, a number of countries are considering—or, in the case of Finland (see YLE, 2009), have recently established—a legal right to broadband internet access, on the grounds that, in contemporary information societies, internet access is as basic a need as, say, electricity. Infrastructure thus comes to be seen as a placeholder for whatever it takes to roll out new measures for overall improvements in efficiency and quality of life. Once this more generalized function of infrastructure is acknowledged, much of the rhetoric from proponents of nanotechnology has a recognizably 'infrastructural' ring to it. Thus, Mike Roco, a leading nanotech proponent and policymaker, gives as the 'main reason for developing nanotechnology' the advancement of 'broad societal goals such as improved comprehension of nature, increased productivity, better healthcare, and extending the limits of sustainable development and of human potential' (Roco, 2003: 181). Nanoscale science and engineering, which claim to offer 'unprecedented understanding and control over the basic building blocks of matter' (Roco, 2003), thus promise to put in place—both in theory and in practice—the 'ultimate infrastructure', as it were: one that holds out the promise of 'shaping the world atom by atom' and adapting it to our needs.[7]

Does Nanotech have Politics?

In the preceding section, I argued that the ambitions of nanotechnology are intrinsically 'infrastructural' in character, insofar as (future) nanotechnology is regarded, by its proponents as well as by policymakers, as a means to the provision of improvements in efficiency and quality of life, including on such basic measures as productivity, health, and life expectancy. However, there is a more specific sense in which nanotech efforts may be considered 'infrastructural', and that is in respect to the organization and funding of science. Much of contemporary scientific research requires considerable financial resources, and the steady provision of such funds is an important factor in the success especially of long-term research programmes. With more and more science funding being allocated on a project basis, there is increasing pressure on scientists to conform to the goals and expectations of funding bodies, and to draw on all available sources of funding. The overall 'funding environment', thus, plays an ever-increasing role in determining the scientific infrastructure that researchers rely on in the planning and conduct of their research. Earlier, it was noted that national nanotechnology efforts began as a political initiative to address imbalances in funding for the biomedical sciences and the physical and engineering sciences. In the present section, I want to suggest that nanotechnology is political not only in origin, but also in a variety of ways relating to the dynamic between the various groups and interests involved.

In an influential paper, 'Do artifacts have politics?' (from which the title of the present section is derived), Langdon Winner (1980) has defended the idea that technological artefacts—rather than merely the actions or intentions of their users—can have political qualities. Winner distinguishes between two broad ways in which this may come about. First, it may be the case that 'specific features in the design or arrangement of a device or system could provide a convenient means of establishing patterns of power and authority in a given setting'; second, there may be other scenarios in which 'the intractable properties of certain kinds of technology are strongly, perhaps unavoidably, linked to particular institutionalized patterns of power and authority' (Winner, 1980: 134). In the first class of cases, the technologies employed allow for some degree of flexibility, and the choices that enforce certain patterns of power relations reflect the political attitudes of the relevant decision-makers. Thus, to use Winner's example, when Robert Moses was tasked with creating a system of parkways and bridges connecting Long Island to New York City, a variety of technological choices were available to him; his decision to build a number of low-hanging overpasses that would keep out public buses (and thereby their passengers, mainly poor people and blacks) was not determined by engineering constraints but by Moses's (alleged) class prejudice and racism.[8] By contrast, Winner argues, certain technologies such as nuclear power, irrespective of their particular designs and implementations, are conducive to certain institutionalized patterns of power and authority, such as a hierarchical and centralized form of social organization, in which the concern for nuclear security trumps all other considerations. In this second class of cases, the initial decision to adopt a general *kind* of technology—irrespective of its particular design or realization—already precludes genuine choice between different social and political arrangements, since the technology in question would not be operable without the relevant social and political parameters held fixed.

A further important political aspect of artefacts concerns the legitimatory function of technology. To some extent this is implied by the second class of cases distinguished earlier: after all, once a technology has been put in place that precludes certain social and political arrangements, the brute fact of its existence may then be used to deny the legitimacy, or viability, of those incompatible arrangements. As Winner puts it: 'After a certain point, those who cannot accept the hard requirements and imperatives will be dismissed as dreamers and fools' (Winner, 1980: 134). The acceptance of some technologies rather than others, thus, brings with it a certain constriction of the political imagination. This is evident in the way in which politics itself becomes increasingly identified with the pursuit of particular technologies. Jürgen Habermas, in his essay 'Technology and science as "ideology"' (1970), written at the height of the modern welfare state, argued that the success of political practice, as well as its overall legitimacy, would increasingly be measured in terms of its proficiency in providing solutions to what would be construed as technical problems. Political issues themselves would be framed not in substantive terms—as competing visions of what would constitute a desirable political and social commonwealth—but in technical terms, as issues that require management, not genuine debate. Technology comes to function as an ideology for the modern industrialized state, insofar as it delimits the scope of political debate: only what is 'technically feasible'—where this is judged not in absolute terms, but by its compatibility with the *status quo*—may legitimately be put up for consideration.

Both Winner's and Habermas's analyses need to be placed in their respective historical contexts. While Winner (1980) writes against the backdrop of growing anti-nuclear sentiment and public protests in many Western countries during the 1970s, Habermas's 1970 text predates the shift away from Keynesian social democracy towards neoliberalism as the main paradigm of governance in industrialized democracies (on this point, see Fisher, 2007). How, one might wonder, can Winner's and Habermas's historically contingent insights help shed light on the political character of contemporary nanotechnology? In what follows, I shall proceed by noting relevant contrasts and similarities between the case of nanotechnology efforts and the cases discussed by Winner and Habermas. In particular, I shall be paying attention to the dynamics between the various actors involved in the discourse about nanotechnology, as well as to the fragmented nature of the relevant publics. This contrasts with the 'static' accounts of both Habermas and Winner, which construe the political dimension of technology either in abstract terms, as the result of an inappropriate imposition of purposive-technical rationality on the practical-political sphere (Habermas), or as due to the conflict between groups with relatively stable political interests (such as Winner's example of the nuclear industry). The case of nanotechnology, by comparison, is considerably more muddled. Unlike nuclear science and technology—which perhaps is the 'purest' example of twentieth century 'Big Science'—nano-scale science and technology is considerably less centralized in terms of its institutional organization. Furthermore, given that contemporary nanoscale science and technology, as discussed in the section 'Imaginary ancestry vs real history', originated from the combination of existing branches of physics, chemistry, and the engineering sciences—which were re-designated as 'nanoscience'—with genuinely new research agendas, it should come as no surprise that nanotechnology presents a more mixed picture also in relation to the political interests and values it embodies.

In the case of nanotechnology, those who have analysed public perceptions of the associated technological risks, have sometimes tended to run together scientists' and policymakers' representations of nanotechnology. Indeed, where the focus is on media representations of nanotechnological risks—including worries about self-replicating nanobots and sensationalist scenarios of uncontrollable 'grey goo' engulfing the world—this may well be partially justified: scientists as well as policymakers share an interest in suppressing representations of outlandish 'worst case scenarios', especially when these lack scientific merits.[9] Upon closer inspection, however, it quickly becomes clear that the alignment between the interests of scientists and those of policymakers is not nearly as complete as their united response to media representations of nanotechnology might suggest.[10] What one finds instead is that scientists have actively, and creatively, co-opted the rhetoric of policymakers and funding bodies, in order to pursue their own (not necessarily disinterested!) choices of research topics. A telling, if anecdotal example, concerns the origins of Singapore's Institute of Bioengineering and Nanotechnology (IBN). When the chairman of the Singapore government's Agency for Science, Technology and Research (A*Star), Philip Yeo, made a proposal in 2002 to Jackie Ying, then one of the youngest full professors at MIT, to spearhead a new 'Institute of Bioengineering' in Singapore, her only request reportedly was: 'Can we make it "Institute of Bioengineering & Nanotechnology?"' (Tan, 2009). One might be tempted to regard such creative appropriations, by scientists, of the nanotechnology agenda as an expression of their overall independence from the pressures of science policy. After all, as Michael Polanyi argued in his classic defence of self-governance of what he dubbed 'The Republic of Science', scientists, by 'freely making their own choice of problems and pursuing them in the light of their own judgments, are in fact co-operating as members of a closely knit organization' (Polanyi, 1969: 49). However, where Polanyi, following Adam Smith, posited 'an invisible hand' that would ensure 'that the pursuit of science by independent self-co-ordinated initiatives assures the most efficient possible organization of scientific progress' (1969: 51), contemporary scientists find themselves guided not by an 'invisible hand', but by an elaborate (and, on occasion, arcane) funding infrastructure that needs to be skilfully manipulated and that demands constant attention—as well as a considerable amount of 'second-guessing' of the intentions on the part of funding bodies.

Science communication—whether in terms of 'public understanding of science' or 'public engagement' with an eye towards envisaged economic benefits—as well as funding mechanisms both require, for their proper functioning, some level of agreement among scientists, funding bodies, and policymakers as to what constitutes legitimate nanoscale science and technology. Given that such agreement is only gradually emerging, there remains considerable flexibility and fluidity at the margins. On the one hand, this has meant that much of the debate about the opportunities and risks posed by nanotechnology has been carried out under conditions of uncertainty, pitting the primacy of precautionary measures against utopian hopes for technological fixes of important global problems. This gives rise to an obvious political dimension in terms of the need for regulatory decisions, for example concerning the extent to which new substances may be deployed in the environment. On the other hand, and perhaps less obviously, nanotechnology has provided a new focal point for 'traditional' political tactics and manoeuvres. Thus, political actors at various levels, many with divergent agendas, have rallied around nanotechnology as something that lends itself to instrumentalization for extraneous political purposes. In much the same way that scientific controversies about the risks and benefits of genetically modified foods have provided fodder for the familiar debates between protectionists and free-trade fundamentalists, commercial nanotechnology may well become the next big arena where national economic interests play out under the pretexts of regulation and free trade, respectively. Below the state level, one finds a diversity of non-governmental interest groups that have co-opted the nanotechnology debate for their own purposes. Thus, as Guillermo Foladori and Edgar Záyago have argued in a recent paper, various trade unions have issued calls for a moratorium on the commercialization of nanotechnologies, partly in order to draw fresh attention to long-standing issues such as safety in the workplace and worries concerning 'the concentration of production and the fate of small producers and workers' (Foladori and Záyago, 2010: 166).

Nanotechnology, thus, may be said to have a range of political aspects, depending on the chosen level of analysis. At the macro-level of national governments and long-term competition between political economies (such as the US, Japan, and the European Union), the emergence of nanotechnology can be seen as, at first, a response to, and later a driver of, disparities and shifts in funding patterns, both between different countries and across disciplines. At the meso-level of funding bodies, corporations, trade unions, and various non-governmental organizations, a plethora of political uses of the nanotechnology discourse abound—some of which are specific to the subject matter of nanotechnology, while others freely extrapolate beyond the immediate technological applications at hand. Future micro-level analyses will need to look in detail at specific nanotechnologies, their commercial deployment, and the particular uses to which individuals put them (which may differ to a greater or lesser extent from those envisaged by the developers). Given that commercial applications of nanotechnology are, for the most part, still in their infancy, I shall here only hint at possible ways in which contemporary nano-scale science and technology may be said to introduce certain ideological biases and blind spots, which may eventually find their way back into society-at-large, once nanotechnologies become more widespread.

Certain effects may be expected simply on the basis of previous experiences with technological change and newly emerging scientific disciplines. At an epistemic level, the focus on novel phenomena at the nano-scale may lead to a selective blindness towards other parameters, such as macroscopic variables of the target systems and their environment. This may lead to a loss of overall understanding of the systems in question and disunity in the way they are conceptualized. Some authors (including scientists, see Cotterill, 1995) have claimed that something very much like this has occurred in biology, where the overwhelming success of molecular biology has led to a loss of expertise in more traditional methods and sub-disciplines, such as taxonomy and systematics. Similarly, when it comes to the commercial deployment of nanotech products, there is the legitimate worry whether existing nanotech R&D is devoting sufficient resources to studying the systemic consequences of the large-scale production, and emission, for example, of nanoparticles.[11] Finally, at the legal level, it seems plausible to expect controversies about the patentability of fundamental nano-techniques, such as procedures for the manipulation of substances at the molecular level, or for constructing pathways of self-replication of 'nano-bots'. Given nanotechnology's ambitious goal of 're-engineering' the world at its most fundamental level, 'atom by atom', such controversies will likely be at least as heated as current arguments about, say, the patentability of genetic information.

Moving from fairly specific effects to a more general level of analysis, it seems fair to say that current nanotech efforts are associated with an inflated, perhaps even excessive, faith in technological solutions. This is the result, at least in part, of the vagueness that attaches to the extension of the term ‘nanotechnology’: If ‘nanotech’ is equated with the manipulation of matter at its most fundamental level and with the creation of new phenomena that can be reliably exploited in a controlled fashion, then its potential for providing solutions to all sorts of problems seems limitless. A good example of this sentiment is Roco’s remark, quoted in the preceding section, according to which nanotechnology derives its *raison d’être* from its contribution towards ‘broader societal goals’, such as ‘increased productivity, better healthcare, and extending the limits of sustainable development and of human potential’ (Roco, 2003: 181). It is important to realize that such faith in the problem-solving powers of nanotechnology goes beyond ordinary belief in technological progress. What distinguishes the nanotech discourse from other discourses about technological progress is the strong conviction that, as nanotechnology progresses, the way we conceive of problems itself needs to undergo a transformation. This transformative aspect of the nanotech narrative is perhaps most evident in the writings of nanotech advocates such as Eric Drexler, who is openly revisionist about the way we should conceive of problems in the world, as well as of our place in nature. In a typical passage, which gestures towards the medical potential of nanotechnology, he writes:

> The ill, the old and the injured all suffer from misarranged patterns of atoms, whether misarranged by invading viruses, passing time or swerving cars. Devices able to rearrange atoms will be able to set them right. (Drexler, 1990: 99)

The idea that problems are best resolved by reconfiguring the microstructure that underlies macroscopic states of affairs is a theme that runs through much of the literature on the prospects of nanotechnology. Early on in his book *Engines of Creation*, Drexler employs the same ‘universalizing’ move to suggest that normative questions of value, too, are eventually decidable on the basis of the microconstitution of matter, given that, ‘throughout history, variations in the arrangement of atoms have distinguished the cheap from the cherished, the diseased from the healthy’ (Drexler, 1990: 3). This deeply revisionist idea is thought to be made more palatable by emphasizing that ‘[o]ur ability to arrange atoms lies at the foundation of technology’: ‘We have come far in our atom arranging, from chipping flint for arrowheads to machining aluminum for spaceships’ (Drexler, 1990). Nanotechnology is thus presented not only as a panacea for all kinds of technological problems but also as the inevitable outcome of a deterministic evolution from simple tool use to highly complex technology with the power to transform the world around us. On such a view, science policy and decision-making in general are reduced to merely ‘enacting’ what will invariably come to pass anyway. Attempts to conceive of issues such as ‘healthcare’, ‘sustainable development’ and ‘human potential’ (to use Roco’s examples) in other than material terms—for example as issues of distribution rather than overall production—have no place within this ideological framework. 'Nanotechnological determinism', it seems fair to say, displays a curious tendency to ignore the very real world of macro-level properties and relations.

Dreams of 'Convergence': Nanotechnology as a Promissory Undertaking

Nanotechnology derives much of its seductive power from its character as a promissory undertaking. Belief in the technological promises held out by nanoscience unites even those who have clashed over various other aspects of the field of nanotech research. A case in point is the much-publicized Drexler–Smalley dispute about the feasibility of precise 'molecular assemblers' that would pick up and re-position atoms individually. Whereas Drexler posits that artificial molecular assemblers must be possible, given that intracellular processes in nature achieve much the same outcomes (albeit in the highly constrained environment of the biological cell), Smalley, in response to an open letter from Drexler, points out that one 'cannot make precise chemistry occur as desired between two molecular objects with simple mechanical motion along a few degrees of freedom' (Smalley, 2003: 40). Yet, despite such serious differences about the prospects of 'dry' nanotechnology (outside biological systems), Smalley and Drexler are in broad agreement about the limitless opportunities afforded by a nanotech future, with Smalley striking a Drexlerian note in his 1999 testimony before the US House of Representatives (see the section 'Imaginary ancestry vs real history'), arguing that nanotechnology 'will revolutionize our industries, and our lives', once we have learnt 'to build things at the ultimate level of control, one atom at a time'.

Drexler, in particular, has long been known for the utopian element in his technological projections. On occasion, his visions take on an overtly anti-modern flavour:

> Nanotechnology will open new choices. Self-replicating systems will be able to provide food, health care, shelter, and other necessities. They will accomplish this without bureaucracies or large factories. Small, self-sufficient communities can reap the benefits. One test of the freedom a technology offers is whether it frees people to return to primitive ways of life. Modern technology fails this test; molecular technology succeeds. As a test, imagine returning to a stone-age style of life—not by simply ignoring molecular technology, but while using it. (Drexler, 1990: 235)

Nanotechnology is thus envisaged as both the inevitable outcome of a predictable course of technological development, and as heralding a new era of freedom—including the freedom to opt out of modern society, without thereby sacrificing one's material comforts. In the Drexlerian self-understanding of nanotechnology, a direct line leads from Feynman's vision of nanotech 'Waldos'—tiny, tele-manipulated robots, designed to achieve specific goals with minimal expenditure in terms of energy and resources—to a new Walden, with its Thoreauean promise of a simple and self-sufficient life (albeit aided by the invisible substrate of all-pervasive nanotechnology). As other commentators have noted, '[t]here is a curious, though surely quite common, mixing of technological and social determinism in this way of arguing' (Mody, 2004: 118). The technological determinism is in evidence when Drexler writes that '[s]ome force in the world (whether trustworthy or not) will take the lead in developing assemblers; call it the "leading force"' (Drexler, 1990: 182). The suggestion is that whoever takes the lead in developing self-reproducing nanobots is merely 'enacting' an unavoidable sequence of steps towards a nanotech future. At the end of this progression, however, a future a radical freedom awaits—one in which technology manifests itself not as an independent force in history, but as a merely enabling substrate that blends in with the choices and lives of individuals. On this view of 'nanotech determinism', technological innovation is the proverbial ladder that can be thrown away at the end of history.

The unifying effect of conceiving of nanotechnology as a promissory undertaking goes beyond the forging of alliances at the individual level. Indeed, the discounting of immediate technological challenges in favour of an envisioned future utopia of technological perfection—what Mody calls 'nanotechnology's non-presentist orientation' (Mody, 2004: 109)—is a familiar theme from science-fiction literature, where it is often coupled with the prediction that different technologies will eventually converge on the same results and goals. Proponents of nanotechnology often speak of 'the nanocosm' and help themselves to the same aesthetics and visual language as science-fiction movies (for example in their computer simulation graphics), thereby inviting parallels with earlier technological movements that have inspired the general public, such as the space programme. Schummer (2009: 59) proposes, albeit only in passing, something akin to a *deficit model* of the emergence of the nanotech movement, when he suggests that the explosion of the space shuttle Challenger in 1986 and the subsequent loss of confidence in the space programme, along with a general sense of disenchantment with Artificial Intelligence research, created a collective need for a new technological imaginary onto which futurists could project their hopes and aspirations. Thus, from the late 1980s onwards, 'nanotechnology' became a focal point for 'a diffuse community of visionaries, recruited mainly from the ranks of apologists and lobbyists for space colonization and research, along with proponents of robotics, Artificial Intelligence (AI), and cryonics' (Schummer, 2009: 58; my translation).

The inclusion of cryonics in this list points to another member in the unlikely alliance between nanotechnology and popular culture: the transhumanist movement. Itself an umbrella term for a variety of cultural outlooks, philosophical viewpoints, and lifestyles, 'transhumanism' has in recent years primarily become associated with the question of whether the expected convergence between nanotechnology, biotechnology, information technology, and cognitive science (or 'NBIC', for short), ought to be exploited for the purposes of 'human enhancement'. Transhumanism answers this question in the affirmative. According to one of its more prominent proponents, transhumanism holds that

> …current human nature is improvable through the use of applied science and other rational methods, which may make it possible to increase human health-span, extend our intellectual and physical capacities, and give us increased control over our own mental states and moods. (Bostrom, 2005: 202)

Relevant technologies for human enhancement are thought to 'include not only current ones, like genetic engineering and information technology, but also anticipated future developments such as fully immersive virtual reality, machine-phase nanotechnology, and artificial intelligence' (Bostrom, 2005). While Nick Bostrom sees transhumanism as indebted to 'secular humanism and the Enlightenment' (Bostrom, 2005), many of its popular manifestations have strong salvationist overtones. Continued augmentation and enhancement will eventually allow the human species to transcend its limitations, giving rise to a state of 'posthumanity', in which human capabilities have been radically transformed. Interestingly, the 'proof of concept' for many of the envisaged technologies—such as Drexler's favourite idea of cryogenically preserving corpses, to be reanimated and rejuvenated (and perhaps enhanced?) once the relevant technologies become available—often consists in the appeal to extant biological systems, such as ourselves. As George Whitesides puts it:

> [T]he issue is not whether nanoscale machines can exist—they already do—or whether they can be important—*we often consider ourselves as demonstrations that they are*—but rather where we should look for new ideas for design. (Whitesides, 2001: 79; italics added)

Nanotechnology, as conceived by transformational futurists, thus not only shapes the world 'atom by atom', it also recreates it in our own image: the envisioned state of 'posthumanity' is simultaneously the perfect union between humans (or their successors) and technology.

The transhumanist visions of individual nanotech proponents will likely strike many readers as outlandish. However, it is worth considering that the general idea—that technology should not merely improve, but 'radically alter the human condition'—has considerable traction with a sizeable portion of the relevant publics. Thus, it has been claimed that elements of transhumanist medicine 'are already embedded in the mainstream North American health research agenda, resulting in a recent shift towards "enhancement" medicine' (Kerr and Wishart, 2008). In the remainder of this section, I wish to briefly point out another—no less significant—ideological affinity of nanotechnology in its relation to converging technologies and their impact on human lifeworlds, namely its affinity with neoliberal market ideology. Several factors are relevant in this respect. First, it is clear from the origins of nanotech funding efforts that, unlike previous public investments in emerging technologies (such as nuclear technology in the second half of the twentieth century), investments in nanotechnology were driven by a fear, not of military defeat, but of economic loss—of losing out in the global marketplace. Second, even though nanoscience, with its language of 'shaping the world atom by atom', trades on the idea of 'finding out what holds the world together at its core'—a slogan that used to be associated with ('pure') particle physics—its rationale depends fundamentally on the prospect of finding commercially viable applications. Third, and perhaps most compellingly, some of the basic assumptions and rhetorical tropes of the nanotechnology discourse tie in smoothly with familiar strategies of legitimating non-interventionist *laissez-faire* economics. My claim is not that the case of nanotechnology is unique in this respect; rather, it is an example of a broader trend in the discourse on technology, namely of the tendency to run together issues of technological convergence and social-political development. This trend finds its perhaps clearest expression in the convergence between the 'digital discourse' concerning information technologies and neoliberal advocacy of the 'global network economy', according to which—in a phrase quoted approvingly by Thomas Friedman, one of the foremost proponents of this development—'the Internet offers the closest thing to a perfectly competitive market in the world today' (Friedman, 2000: 81).

Eran Fisher, in an insightful analysis of the ideological underpinnings of digital discourse, notes that the discourse on information and communication technology 'offers a renewed confidence in the market' as a 'medium of economic and social life' by reasserting 'the superiority of the market—frictionless, unhindered, and most importantly insulated from any political intervention' (Fisher, 2007). In much the same way that neoliberal theory regards markets as self-regulating mechanisms that instantiate a higher degree of rationality than any individual would be capable of, proponents of the network economy assert—without offering more than anecdotal evidence—that 'swarm intelligence', 'smart mobs', and the 'wisdom of the crowds' will eventually lead to more adaptive decision-making and better outcomes than could be achieved through regulation and fixed procedures. In both cases, belief not only in the possibility, but in the superiority of 'spontaneous order' (as opposed to centralized design) plays a central legitimizing role. Friedrich Hayek, in his influential article on 'The Use of Knowledge in Society', argued that 'in a system where the knowledge of the relevant facts is dispersed among many people' (Hayek, 1945: 526), only a market-like mechanism could guarantee that existing knowledge is aggregated properly, and acted upon in the most efficient way. The 'problem', as Hayek puts it, is not how to engineer desirable outcomes but 'how to dispense with the need of conscious control and how to provide inducements which will make the individual do the desirable things without anyone having to tell them what to do' (Hayek, 1945: 527).

In the discourse on nanotechnology, 'self-organisation' (with or without self-replication) functions as the analogue to 'spontaneous order' and is expressed most programmatically in Drexler's concept of the molecular assembler. While such devices would, in the first instance, still rely on human intervention for their coming into existence, they would achieve their various tasks largely autonomously. If programmed to self-replicate, molecular assemblers, it is thought, would have the ability to evolve adaptively, acquiring new functions along the way. Collectives of nanodevices would, in this respect, behave more like 'smart mobs' than like traditional technological systems that were designed in a top-down way. It is these characteristics that, in Drexler's utopian vision, allow future '[s]elf-replicating systems … to provide food, health care, shelter, and other necessities'—all 'without bureaucracies or large factories' (Drexler, 1990: 235). The implication is clear: Whereas old technologies require large factories and centralized (state?) bureaucracies, nanotechnology meets the demands of its users (customers?) right at their doorstep, thereby allowing '[s]mall, self-sufficient communities' to 'reap the benefits' (Drexler, 1990). Once again one is reminded of Hayek, who similarly forges a link between conditions of 'spontaneous order' and the flourishing of self-sufficient voluntary communities: 'It is the great merit of the spontaneous order concerned only with means that it makes possible the existence of a large number of distinct and voluntary value communities serving such values as science, the arts, sports and the like' (Hayek, 1976: 151). Perhaps, then, Drexler's posited 'leading force' that will inevitably push technology towards the development of self-organizing molecular assemblers is just one of those forces—along with 'various religious creeds', 'traditions', and 'superstitions'—that, as Hayek puts it, 'we cannot hope fully to understand, yet on which the advance and even the preservation of civilisation depend' (Hayek, 2010: 154).

Conclusion

Nanotechnology has had a stellar career over the past two decades. From a largely speculative pastime of science enthusiasts and science-fiction aficionados, it has developed into a multi-billion dollar research programme that is reshaping large swaths of science, at the institutional as well as the conceptual level. As I have attempted to show in the present paper, the emergence, allure, and implications of nanoscale science and technology can only be fully appreciated if one approaches it from a perspective that goes beyond immediate technical and scientific payoffs to also include infrastructural and ideological considerations. As one recent group of commentators put it, the expectations of nanotechnologies are 'in essence, a *social performance*—one that is sustained through a diverse array of activities for promoting narratives of where the technologies are heading and who will benefit' (Anderson et al., 2009: 130). As discussed in the section 'Dreams of "convergence"', nanotechnology is fundamentally a promissory undertaking; as such, it resonates with other future-oriented discourses, not least those of social, political, and economic progress. With its emphasis on the transformational character of 'bottom-up' processes such as self-assembly and self-replication, nanotechnology closely parallels ideas of 'spontaneous order' in the social and political realm and lends them credibility via the invocation of technological determinism. Indeed, one might say, nanotechnology's advocates 'build networks of people and institutions *through* determinist talk and action, and in doing so they conjure up the thick social ties that make such determinism plausible' (Mody, 2004: 103). Despite nanotechnology's utopian ambition to create a better world—one in which many of our contemporary problems will have found effortless and affordable solutions—it is well worth pondering what hidden costs and consequences are associated with the pursuit of nanotechnology and converging technologies. For one, there is the issue of unequal access to new technologies of human enhancement at the individual level, which may result in an eventually unbridgeable gap between (posthuman) 'haves' and those 'have-nots' who have not profited from enhancement technologies in the same way. More pressingly, however, there is the very real risk that, as with biotechnology, gene patenting, and information technology, whole countries and regions might find themselves cut off from technological innovation. Taking the global distribution of health-related nanotechnology patents as an indicator, one finds the familiar pattern of US and European domination with a total share of around 70 per cent of patents (2004 figures). What is perhaps more surprising is that virtually all of the remaining 30 per cent are accounted for by Asian companies and institutions, with only 0.3 per cent of patents held by South America, Africa, and Oceania combined (see Maclurcan, 2005). Assuming that such trends will likely continue in the future—and there is little to suggest that they will cease to do so—they bring out with brutal clarity just how much of a gap still exists between the utopian vision of universal empowerment of self-sufficient communities and contemporary nanotechnological practice in a global context.

NOTES

1. On this point, see Schummer (2009), esp. Chapter 5.
2. Quoted from Schummer (2009: 19), my translation.
3. See McCray (2005: 187).
4. Quoted from McCray (2005: 186).
5. Predictably, this has led to the renaming of research institutes, such as the University of Manchester Institute of Science and Technology Centre for Microporous Materials, which is now called 'Centre for Nanoporous Materials' (see CNM's website at http://www.chemistry.manchester.ac.uk/groups/cnm/about.htm, accessed on 15 August 2010).
6. On the notion of 'Kuhn loss', see (Laudan, 1991).
7. The phrase 'shaping the world atom by atom' was popularized by the title of the NSTC's first brochure advocating nanotechnology (NSTC, 1999).
8. The historical accuracy of Winner's portrayal of Moses has since been challenged; see (Joerges, 1999).
9. A similar case would be the bizarre worry, jointly dismissed by scientists and policymakers, that the operation of CERN's new particle accelerator in 2009 might lead to the creation of a black hole that would then swallow up all matter in its vicinity.
10. On scientists' views on news coverage of nanotechnology, see Anderson et al. (2009), specially pp. 115–25.

11. This worry is compounded by the first product recalls of self-proclaimed 'nano-tech' consumer products, such as sprayable household products, most with dubious nanotech credentials. (See Gammel, 2009.)

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