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Nanotechnology, Governance, and Public Deliberation: What Role for the Social Sciences?

In this article we argue that nanotechnology represents an extraordinary opportunity to build in a robust role for the social sciences in a technology that remains at an early, and hence undetermined, stage of development. We examine policy dynamics in both the United States and United Kingdom aimed at both opening up, and closing down, the role of the social sciences in nanotechnologies. We then set out a prospective agenda for the social sciences and its potential in the future shaping of nanotechnology research and innovation processes. The emergent, undetermined nature of nanotechnologies calls for an open, experimental, and interdisciplinary model of social science research.

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Social science historically developed alongside the new industrial order, which was based on novel technologies of steam-based power, the railways, and the factory system. Marx analyzed this new technological society

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as it unfolded around him in mid-nineteenth-century Britain. However, during the twentieth century, social science often struggled to keep pace with new and emerging technologies. It was slow to provide intelligent and reflexive analysis of the implications of personal automobility, the splitting of the atom, and the significance of early computing.

In this article we argue that nanotechnology represents an extraordinary opportunity to build in social science insight from the outset. By thinking of its role in a new way and taking the reflexive governance of nanotechnologies as a central concern, social science has novel opportunities to become an actor in these changes and to provide insights that are simultaneous with scientific, technological, and social changes.

However, analysis of all such "technosocial orders" presents significant challenges to existing ways of doing social science, especially in the outmoded idiom of seeking to examine a categorically social realm as distinct from physical and material elements (Latour 2004). Historically, the academic literature has framed technology as "black-boxed" and well defined, with an independent asocial logic that results in "impacts" or "effects." Social questions are often narrowly framed as "impacts" or "risk" issues, placing the site of social science inquiry firmly "downstream" of innovation processes (for a recent nanotechnology example, see European Commission 2004). However, various approaches in science-and-technology studies have shown how technologies cannot be black-boxed and separated from sets of constitutive social relations (see Law and Hassard 1999; Pinch and Bijker 1984; Wynne 1988).

"Constructive technology assessment" (Rip, Misa, and Schot 1995) and "real time technology assessment" (Guston and Sarewitz 2002) represent two approaches that problematize the determinism of black-boxed technology. Both approaches focus on how "technical" processes often make implicit upstream assumptions about the social uses to which the technology will be put: under what conditions, by which kinds of actor, and with what aims (Grint and Woolgar 1997; Law and Bijker 1992). Social and political relations, or imagined relations, are "hard-wired" into technological designs, and performed by them (Winner 1977). Science-and-technology theorists suggest that a fundamental characteristic of any technology is its heterogeneous, hybrid mix of material, social, and discursive relations, its mix of pure and applied elements, and its associated and often prescriptive social expectations or assumptions (Latour 2004; MacKenzie and Wajcman 1999). The

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goal of such processes is to engage forms of public participation before innovation processes become locked in—in other words, at an upstream stage. In this article we set out and critically engage with the notion of "upstream public engagement" as a further and potentially useful addition to the unfolding academic and policy debate.

Such a conceptual approach lies in stark contrast to the more limited role of the social sciences that tended to characterize its use in the development of biotechnologies. Dominant approaches, institutionally cemented through programs aimed at understanding the ethical, legal, and social issues (ELSI) surrounding the Human Genome Project, locked into a framing that assumed the technology as a given, and as such, assumed the project of ethical and social reflection as one largely reduced to conceptualizing, evaluating, and managing "the impacts." Through such framing commitments, ELSI programs lacked any mechanism to affect the innovation process itself. Relatedly, the birthing of "bioethics" that arose out of this agenda has been largely complicit with deficit models of science communication (Hedgecoe and Martin 2003; Wynne 2001). Indeed, we have argued elsewhere that the framing of the social sciences in the development and utilization of genetically modified (GM) crops and foods was such that its mobilization was often too late and without any real purchase on on-going processes of governance (Kearnes et al., forthcoming).

More generally, in the domain of biotechnologies, there was little institutionally sanctioned space for the social sciences to engage with wider social and political questions about purposes, ownership, control, and responsibility (Grove-White et al. 2000; Wilsdon and Willis 2004). *Why these technologies? Why not others? Who needs them, and what human purposes are driving them? Under what conditions will they be enacted; and who sets those conditions? Who is controlling them? Who benefits from them? Can they be trusted?* Drawing on the lessons from GM and other controversies, nanotechnology reflects an opportunity for the social sciences to explore how governance and regulation can be extended to incorporate a wider set of cultural and social, and indeed technical, factors (Grove-White et al. 2004). We suggest that unless this challenge is addressed, the latent tensions inherent in the technological transformation of democratic society are likely to remain unaddressed. Far from being a "critical" project, therefore, this is a constructive one, requiring robust collaborative interactions with scientists and technologists.

Significantly, there appears to be some institutional recognition of the need for a wider role for the social sciences in the development of nanotechnologies, including a clear undertaking for novel forms of public dialogue and engagement (see Department of Trade and Industry/Office of

Science and Technology 2005; Royal Society/RAE 2004). In this article we address some of the underlying machinations and rationales at work for building social science into the development of nanotechnology. These include:

- The appeal to social scientists as experts in the study of public opinion and political mobilization processes, hence leading to promises that such socially sensitive intelligence may help avoid future disruptive public controversy;
- The ability of social science to help shape innovation processes in tune with wider public and consumer attitudes, thus helping governments and corporations "pick winners" and "avoid losers";
- The exploitation of social scientists as (good) public communicators and disseminators of nanoscience and nanotechnologies, often in an outreach capacity, thus again helping shape a more informed and arguably less emotive but not necessarily less critical public debate;
- The attempt to use social science techniques to open up the "black box" of science and innovation, so that tacit assumptions shaping its development can be opened to wider public scrutiny, to induce greater reflexive awareness among scientists in their specialist work worlds, with the expected result that innovation processes indirectly gain added sensitivity to human needs and aspirations, and thus greater resilience and sustainability.

The distinctions between these framings are, of course, ambiguous—indeed, most are at play in different ways in multiple contexts. Similarly, it is an open question which of these framings will come to the fore and dominate. In this sense nanotechnology represents an opportunity to innovate new and more reflexive relationships between the social sciences and the physical sciences. However, despite this renewed openness to social science input, there is a danger that such input is framed in ways that assume the *prima facie* beneficence of technology and that would seek to limit the scope for social science input to disturb core innovation processes. We argue below that in both the United States and United Kingdom there is an emerging dynamic aimed at both opening up, and closing down, the role of the social sciences in shaping future nanoscience and nano-innovation research agendas and trajectories. We then set out, in programmatic form, what a more open-ended agenda for the social sciences of nanotechnologies might look like.

The Public Debate

In the past two years, a policy and media debate about nanoscience and nanotechnologies has emerged, characterized by competing visions of promise and threat. For their advocates, nanotechnologies are seen to have huge economic and social potential, ushering in a "new industrial revolution" that will include breakthroughs in computer efficiency, pharmaceuticals, nerve and tissue repair, surface coatings, catalysts, sensors, materials, telecommunications, and pollution control (European Commission 2004; House of Commons Science and Technology Committee 2004; Roco and Bainbridge 2001). Worldwide research funding for nanosciences and nanotechnologies is increasing rapidly, and is estimated to have reached $8.6 billion in 2004 (Lux Research 2004).

At the same time, ethical, social, and environmental concerns that originated with dystopian fears of "grey goo" (Drexler 1986; Joy 2000) are rapidly taking on a sharper focus around the potential toxicity of nanoparticles and the need for tighter regulation (*Nature* 2003; Royal Society/Royal Academy of Engineering 2004). Nongovernmental organizations (NGOs) have criticized the vested interests that lie behind the science, and Prince Charles has raised the specter of thalidomide in an effort to encourage a more precautionary approach (ETC Group 2003; HRH The Prince of Wales 2004).

Such bipolar characterizations are, of course, an oversimplification. The questions, challenges, and opportunities that surround nanotechnologies will take many forms. Indeed, the very definitions and constitutions of nanotechnologies are themselves the subject of lively debate, within the scientific community and beyond (House of Commons Science and Technology Committee 2004).

As conventionally understood, the term "nanotechnology" refers to the design or manipulation of structures and devices at a scale of 1 to 100 nanometres (or billionths of a meter). Yet scale is one characteristic that unites the diverse activities and applications commonly referred to in this way. A crucial further issue is the novelty and unpredictability of what occurs at this scale. When broken down into such small particles, the properties of materials can change in fundamental ways. Gold and silver are good examples. Normally inert and unreactive, at the nanoscale gold acts as a highly effective catalyst, and silver displays bioactive properties (Smith 2004).

Working at this scale requires a high degree of interdisciplinarity, and nanoscience increasingly extends across a range of fields, from chemistry, physics, and biology, to medicine, engineering, and computer science. Yet while the term "nanotechnology" may be relatively new, much of the science behind it is not. Many existing chemical processes have nanoscale features, and nanotechnologies have been used to create computer chips for the past twenty years. From a social science perspective, this raises important questions about the processes through which such terminologies are being defined, contested, and continually adapted in relation to external economic and political drivers.

Given the novelty of what becomes possible at the nanoscale, it is perhaps unsurprising that nanotechnologies are giving rise to new, and potentially profound, social questions. These have moved with remarkable rapidity onto the political and regulatory agenda in the UK, across Europe, the United States, and beyond. Additional complexities flow from the convergence of nanoscale innovations in different domains: notably, the life sciences, cognitive sciences, and information technology (European Commission 2004; Nordmann 2004; Wood, Jones, and Geldart 2003). We now address the policy debate shaping the role of the social sciences in the United States.

The United States

In the United States, the context for research into the social and ethical dimensions of new and emerging technology has been shaped fundamentally by the institutional support and commitment granted to the ELSI program of the Human Genome Project (Ramsay 2001). The ELSI program was established to provide:

> A new approach to scientific research by identifying, analyzing and addressing the ethical, legal and social implications of human genetics research at the same time that the basic science is being studied. In this way, problem areas [would] be identified and solutions developed before scientific information is integrated into health care practice. (National Human Genome Research Institute 2004)

The ELSI approach clearly sets the institutional and intellectual context for current considerations of nanotechnology. As already noted above, however, there remains a fundamental tension at the heart of the approach. Although research is clearly intended to feed social and ethical insight into science-and-technology developments in "real time," it is framed as being able to scrutinize only the *impacts* or *effects* of the technology rather than (as set out above) deeper social and political considerations about driving purposes and visions that may be exercised in shaping knowledge production, as well as broader issues about ownership, control, and responsibility. Rather than being a mode through which social science insights may be "built into" technological development, both upstream and in real time, it is becoming increasingly apparent that the ELSI agenda reduces such scholarship to a downstream "bolt on." In its focus on impacts and effects, the ELSI program assumes the inevitability of prevailing and future forms of technology and limits the role of social science to downstream questions. As such, social science scholarship is invoked only after significant commitments are already made and technological pathways have become locked in, thus without any real purchase on the development of such technologies.

The way that ethical and societal enquiry is positioned in relation to nanotechnology in the United States demonstrates the influence of this approach and the tension therein. The National Nanotechnology Initiative report, *Leading to the Next Industrial Revolution* (National Science and Technology Council 2000), for example, outlines the role of ethical and societal inquiry in the following terms:

> Ethical, Legal, Societal Implications and Workforce Education and Training efforts will be undertaken to promote a new generation of skilled workers in the multidisciplinary perspectives necessary for rapid progress in nanotechnology. The impact nanotechnology has on society from legal, ethical, social, economic, and workforce preparation perspectives will be studied. The research will help us identify potential problems and teach us how to intervene efficiently in the future on measures that may need to be taken. (p. 13; see also Bennett and Sarewitz, forthcoming)

The report further outlines how such research will be carried out in real time, in concert with scientific and technical innovation, and how it will provide early evidence of potential social and ethical "problems" enabling upstream intervention. However, as with the ELSI program of the Human Genome Project, such research is also implicated in the "success" of the federally funded National Nanotechnology Initiative (NNI). That the NNI is, at least rhetorically, to lead to the "next industrial revolution" is not subjected to ethical or sociological inquiry. And in this particular sense, the envisaged role of the social sciences can be seen as a social lubricant in the drive toward industrial success and commercialization. This is a position more or less enthusiastically embraced by Roco and Bainbridge (2001) in their report on the National Science Foundation–sponsored workshop on the "Societal Implications of Nanoscience and Nanotechnology." Indeed, in their introduction to the workshop, Roco and Bainbridge set out the role of social science research in the following terms:

> Research on societal implications will boost the NNI's success and help us to take advantage of the new technology sooner, better and with greater confidence . . . [and later] Nanotechnology's effect on society—legal, ethical, social, economic, and workforce preparation—will be studied to help identify potential concerns and ways to address them. As the NNI is commencing, there is a *rare opportunity to integrate the societal studies and dialogues from the*

> *very beginning and to include societal studies as a core part of the NNI investment strategy.*(pp. 2, 10, emphasis in original)

In this way, although the social sciences are seen as playing a legitimate and potentially integrating role in the development of nanoscience and nanotechnology, such an involvement is still coupled to a relatively unproblematized notion of "success," and to a very downstream vision of the scope for social science that excludes social dimensions of the processes shaping the knowledge and technologies themselves. The positioning of societal and ethical research in this way is, therefore, imbued with the same, unresolved, tension as in the Human Genome Project. Though such research is to be both funded and supported by central government, and positioned in such a way as to promise to influence the trajectory of developments in nanotechnology, it is currently unclear whether such research will be able to achieve the necessary distance from projected innovation roadmaps. The ELSI component of the NNI is framed in a way that makes this tension both ambiguous and unresolved.

Such unresolved tensions can also be identified in the 2003 *21*st Century Nanotechnology Research and Development Act, a largely administrative act designed to authorize appropriations for nanoscience, nanoengineering, and nanotechnology research. While specific legislative clauses are written into the act to ensure that ethical, legal, environmental, and societal concerns are addressed during the development of the technology, it remains unclear as to how and in what ways such an integrated agenda is imagined to impinge on the development of the science agenda itself. Such tensions are currently being played out in 2005 in relation to National Science Foundation proposals for a major $13 million "Center for Nanotechnology in Society," not least in relation to the legal stipulation to consider the potential use of nanotechnology in human enhancement.

To summarize, even though the role of the social sciences in the United States has tended to be framed as limited to the exploration of the societal impacts arising from nanoscience and nanotechnology, there remains significant scope for a wider role due to the parallel ambitions for social research to become integrated with innovation processes in real time. Such ambiguity has created an opening in the normally "black boxed" processes of technological development and innovation, the effect of which will become visible only in the coming years.

The United Kingdom

Although the social sciences benefited from a well-targeted ESRC-funded report on the *Social and Economic Challenges of Nanotechnology* (Wood et al. 2003), it was the publication in July 2004 of the UK Royal Society/Royal Academy of Engineering report on nanotechnologies that signaled the start of a new phase in UK debates on nanotechnology and society. Learning from recent experience with biotechnology, the Royal Society highlighted a key role for the social sciences to help provide improved insights into the implications of nanotechnologies and their role in helping facilitate more socially robust technologies.

This move poses significant challenges and opportunities that are only beginning to be conceptualized. Not least on account of the widespread public ambivalence toward science that is manifest in the UK, to what extent is it possible to create frameworks of governance that can sustain economically vibrant, socially legitimate, and environmentally sustainable technological enterprises? How are individuals and institutions, confronted with rapid technological change, to imagine new social possibilities, and choose among them wisely? And how may all of this pan out for the poor, for developing countries, and for the development process generally. A number of initiatives in the UK have begun research aimed at developing insights on these questions, so as ultimately to generate more socially intelligent processes of regulation, public dialogue, and technology assessment (Department of Trade and Industry/Office of Science and Technology 2005; Macnaghten et al. 2003; Wilsdon and Willis 2004; Wilsdon, Wynne, and Macnaghten 2005).

The policy context in the UK, including its particular preoccupations with "public engagement," needs to be situated within a particular historical context. Following a series of controversies—such as "mad cow" disease and genetically modified crops and foods—there is growing institutional commitment for new mechanisms of public involvement in the social and ethical dimensions of science and technology (Better Regulation Task Force 2003; House of Lords 2000; Royal Commission on Environment and Pollution 1998). More recently, policy discussions have started to focus on the need for public engagement to take place "upstream" in processes of innovation, at a stage when it can influence research decisions, and before entrenched or polarized positions emerge (Grove-White et al. 2000; Wilsdon and Willis 2004; Wynne 2003). For example, the UK government's new ten-year strategy for science and innovation includes a commitment "to enable [public] debate to take place 'upstream' in the scientific and technological development process, and not 'downstream' where technologies are waiting to be exploited but may be held back by public scepticism brought about through poor engagement and dialogue on issues of concern" (HM Treasury/Department of Trade and Industry/Department of Education and Skills 2004, 105). This argument has now been adopted in relation to nanotechnologies by the Royal Society, the Science Minister Lord Sainsbury, and the Office of Science and Technology (Department of Trade and Industry 2004; Department of Trade and Industry/Office of Science and Technology 2005; Royal Society/Royal Academy of Engineering 2004).

These commitments to "upstream" public engagement in processes of scientific-technological innovation are a significant shift in public-policy discourse, and raise many unresolved questions for social science as well as for science itself. At what stages in R&D processes is it realistic to raise issues of public accountability and social concern? How and on whose terms should such issues be debated? Are dominant institutional discourses of risk, ethics, and "social responsibility" adequate for addressing these issues? Can citizen-consumers exercise constructive influence over the pace and direction of technological (and related social) change? How can these questions be reconciled with the need to maintain the independence of science, and the economic dynamism of its applications?

Of course, such a portrayal of UK policy making on nanotechnology and the extended role of the social sciences is only one part of a complex and unfolding set of forces. There is a further and more familiar conservative dynamic at play in which social science is seen as having a far more limited role in the development of nanoscience policy. Indeed, such a view was reflected in the UK government response to the Royal Society/Royal Academy of Engineering report in which the social sciences barely made a mention, where the language of "upstream" public engagement failed to make the final draft, and where no new money was offered (HM Government 2005). Even the Royal Society declared itself "very disappointed" (Royal Society 2005)!

It has been striking to see the rapid official uptake in UK and EU science-policy communities of the idea of *upstream* public engagement with science; an idea that emanated from an extensive academic scholarship in science-and- technology studies and more recently in the writing of key scholars involved in public policy (see Marris et al. 2001; Wilsdon and Willis 2004; Wynne 2001, 2003). However, the more complex shift of focus that an "upstream" focus was intended to introduce has rarely been noticed in this official uptake, and which thus has remained riddled with confusion and ambiguity. This can be noted, for example, in the otherwise admirable UK Royal Society/Royal Academy of Engineering (2004) report on nanotechnologies. Thus, whereas Wynne and colleagues have emphasized that upstream forms of public engagement with science are emphatically *not* pretending to earlier prediction of impacts or social reactions so as better to manage these, the Royal Society/Royal Academy of Engineering report—in a single chapter on public engagement and the need to move upstream—refers to this ambition at least ten times. By contrast, Wynne and colleagues have stressed the logic that the predicament of ignorance and unpredictability—of which ordinary publics appear only too aware (Grove-White et al. 1997; Marris et al. 2001)—implies that we need to develop novel techniques aimed at eliciting, explicating, and subjecting to wider debate and scrutiny, the driving purposes, expectations, imaginations, and social ends of upstream knowledge. Such debate would provide a different ethical and social context for scientific practice, including R&D investment.

Thus, we suggest, upstream engagement does not concern publics telling scientists what to do or think, nor assert that ordinary people know better than scientists about risks, as the prevalent, and blatantly confused, prediction-immersed understanding of upstream engagement with science still mistakenly implies. Rendering scientific cultures more self-aware of their own taken-for-granted expectations, visions, and imaginations of the ultimate ends of knowledge, and rendering these more articulated, and thus more socially accountable and resilient, is a radically different kind of role for the social sciences. This, we argue, lies in science's own best interest, as it would provide the grounds for a public legitimacy that its patrons and exploiters are so anxiously seeking.

What Kind of Social Science is Required?

As we have demonstrated, the science-and-policy debate around nanotechnologies represents a novel opportunity for building the social sciences into its upstream development. As we seek to map out such an agenda, we need to bear in mind that such upstream terrain has traditionally been regarded as properly fenced off from social attention. How can this complex and difficult terrain, as yet uncharted, be addressed in a constructive and responsible way? We conclude this article by setting out a prospective agenda for the social sciences and its potential in the development of nanotechnology research and innovation processes. The emergent, undetermined nature of nanotechnologies—technoscience "in-the-making" (Latour 1987)—calls for an open, experimental, and interdisciplinary model of social science research. From the outset, the ambition is to develop interdisciplinary approaches that seek to embrace the complexities of nanotechnologies, and their emergent, materializing, and condensing social relationships. We now discuss five potentially rich veins of social science research activity:

I. Imaginaries. A social science of nanotechnology should seek to unpack the ways in which nanotechnology is *imagined*—in both technical and social terms—and to assess the role that such imaginaries play in innovation processes. Understanding the implicit assumptions, values and visions—or "imaginaries"—of key actors has been recognized as a central part of the social science challenge, because of their significant role in shaping research and innovation trajectories (Brown and Michael 2003; Hedgecoe and Martin 2003; Kearnes et al. forthcoming; Rose 2001; van Lente 1993).

The term "imaginary" shares the sense of vision and fantasy implied by the term "imagination." But it dissolves the opposition of the imagined and the real: whether an imaginary is based in fantasy or in evidence remains an empirical question rather than one to be settled a priori (Marcus 1995; Verran 1998). The key point is, imaginaries are materially powerful; they do shape practices, relationships, and commitments (which are often rendered irreversible), and as such, they demand reflective, accountable attention and debate.

As well as shaping the expectations of individuals and institutions, imaginaries are mobilized through ongoing public discourses and enacted in everyday practices. They are multiple, partial and often internally inconsistent (Fleck 1979; MacKenzie 1992; Squier 1995, Suchman and Bishop 2000). Emerging technologies, surrounded by ambivalence and conflicting narratives of utopia and dystopia, provide fertile ground in which the moral dilemmas of modernity are rehearsed. While some visions are repeatedly promoted—progress/cornucopia, a world of leisure or the conquest of disease—others may be repressed in official discourse, such as the narratives of Frankenstein or *Brave New World* (Bloomfield and Vurdubakis 1995).

Scientific practice has traditionally been seen as insulated from such cultural forms, yet, whether implicitly or explicitly, it is routinely influenced by them, as for example, the often unstated "cultural" drive of science toward "precision" and "control." A major object is to explore what form and extent this influence takes. How do imaginaries shape trajectories of scientific research, and help define "doable" and worthwhile scientific problems? What role do they play in the allocation of funding? How do they mobilize public and private interest and opposition? And how can social science help open up such imaginaries to wider public scrutiny and debate, for the benefit of science as well as society? In the context of a general dialectic between openness and closure that characterizes any process of innovation, the aim is to open up nanotechnological imaginaries and scientific potentialities *before* they are inadvertently closed down and "black boxed" through commitments to specific problems, products, and applications (Stirling 2005).

Nanotechnologies are framed by scientific and engineering imaginaries that have longstanding antecedents (see, for example, Noble 1977, 1997; Shapin 1994). Their promise is infused with dreams of perfect engineering, of complete control over the physical structure of matter, and, eventually, the creation of autonomous, self-replicating entities. Such imaginaries render nanotechnologies visualizable and to some extent already familiar (e.g., the macrolevel machine expressed at the nano-level). The ability to operate at the nanoscale—atom-by-atom—symbolizes an expression or ambition of power. It represents the material world subordinated to human will with unprecedented degrees of precision and control.

At the same time, this vision of total control is something of a double-edged sword, if not an Achilles heel. For the empirical invisibility of nanotechnology, beneath the threshold of the human senses (rather like genetic modification and nuclear technology before it; see Beck 1992; Erikson 1994), makes it almost impossible to verify whether it is in fact under human control—thus providing fertile ground for voices of opposition; for instance, dystopias that build upon Drexler's imaginary of self-replicating "grey goo" as a central motif. Indeed, whilst this notion of "grey goo" is dismissed by mainstream nanoscientists (Royal Society/Royal Academy of Engineering 2004), it has achieved a certain prominence among the public and media, not least due to interventions by the heir to the UK throne. In debates over GM food, negative popular imaginaries tended to be dismissed or ignored and it would seem prudent that the same mistake is not repeated in the area of nanotechnology.

Such research poses significant methodological challenges, including the development of novel and reflexive relationships with nanoscientists and other relevant actors, both at academic research sites and within corporate R&D settings. To understand the nature, origins, and effects of such imaginaries, and to find ways of opening them to greater scientific reflection and public debate, will require informed interaction with scientific actors in their own "lifeworlds." This implies a potential role for social scientist ethnographers as a new kind of actor-participant in those scientific knowledge communities. Similar developments are afoot in social science research with the postgenomic sciences.

II. Public Engagement. A social science of nanotechnologies should ask in what ways can processes of public dialogue open up and help indirectly to shape "upstream" R&D of emerging nanotechnologies, and seek to build appropriate models of public engagement into the development of nanotechnologies.

Since 2000, when the UK House of Lords *Science and Society* report buried the misconceived *deficit model* of public understanding of science (Wynne 1991, 1995), "public engagement" has become the new mantra (at least in UK and EU science policy). Much of this new "listening mode" for science has been taken up with the aim or expectation of restoring public trust and authority for science. The more radical idea that public inputs might legitimately reshape scientific and technological enterprises as a condition for their public legitimacy has not been a prominent feature of the new discourse of public engagement. The suggestion that public engagement may have several different rationales and objectives, including the stimulation of greater self-reflection *within* science about its own assumptions and expectations, effectively about its own cultural forms, has been made more recently (Wynne 2003). As described before, there is also an emerging consensus that such engagement should be focused on *upstream* processes of R&D priority setting and funding, in addition to the downstream *impacts* of innovation (Department of Trade and Industry 2004; Grove-White et al. 2000; HM Treasury 2004; Macnaghten 2004; *Nature* 2004; Royal Society/ Royal Academy of Engineering 2004; Wilsdon and Willis 2004; Wynne 2001).

However, even though there is increased policy and institutional acceptance of the need to move upstream, precisely what this entails remains ambiguous and open to multiple interpretations. For some, upstream engagement is still assumed to be about earlier anticipation and more effective management of risks, impacts, and consequences. Such assumptions downplay a critical dimension of public concern, which is that there are unpredicted consequences that scientific risk assessment is incapable of identifying, whether it takes place upstream, downstream, or somewhere in between (Marris et al. 2001; Wynne 2001). Instead, publics often want to ask more fundamental questions about driving human purposes, ownership, control, and responsibility. Modern science and technology in general has suffered an unhealthy dearth of any such debate, which has instead been focused on risk.

It has been recognized that nanotechnologies and their convergences with adjacent domains such as Information and Communication Technologies (ICTs) and biotechnologies make prediction of future effects a decreasingly credible aspiration—and this from an unpromising starting point in terms of existing track record (Joy 2000). The claim of reliable predictive control through risk assessment has to be rethought as the basic reflex response of policy and scientific institutions to public concern or hesitation (Guston and Sarewitz 2002; Sarewitz et al. 2000). Upstream public engagement may sometimes help to create the conditions for better risk prediction. But this should not be the primary reason for this change of focus. Rather, it is that upstream processes are key sites of undeliberated shaping of future worlds, as explained in the previous section. If these are to be elicited, debated, and maybe amended, social science needs to develop frameworks of accountability and learning that so far remain undeveloped.

The methodological challenge is to build on a range of "upstream" deliberative methods, involving both experts and public, through innovating novel techniques such as focus groups, citizen juries, scenario workshops, and deliberative mapping (Grove-White et al. 1997, 2000; Macnaghten 2004; Stirling 2005; Stirling, Davies, and Burgess 2004), as well as ethnographic methods. Key research questions that need to be addressed are: How can "upstream" questions be addressed in open, accountable, and resolvable ways? How can conventional forms of risk assessment and ethical analysis be integrated with wider social and political questions about purposes, alternative scientific trajectories, ownership, control, and responsibility? And what lessons can be drawn from technological domains where upstream public engagement is exclusively staged at the downstream stage—as took place, arguably, in the case of GM crops? It is also important to scrutinize what counts as successful public engagement. Is it the avoidance of immediate conflict, or longer-term changes toward greater resilience in the culture and practices of science? (Nowotny, Scott, and Gibbons 2001).

III. Governance. By building social science research into the upstream development of nanotechnology, it will be possible to innovate new frameworks for the governance and regulation of nanotechnologies that seek to be more anticipatory, resilient, and socially intelligent.

Confronted with rapidly advancing and converging nanotechnologies, policy makers and regulators need to identify frameworks of governance that are adaptive and anticipatory, yet which recognize the limits of prediction (Bentley and Wilsdon 2003; Sarewitz et al. 2000). When technological controversies erupt, the usual political response has been to look for regulatory solutions based on familiar science-based techniques of risk assessment. This pattern is already evident in debates around nanotechnologies, which are focusing heavily on regulatory responses to the uncertainties and potential hazards of nanoparticle toxicity (European Commission 2004; Royal Society/Royal Academy of Engineering 2004).

These responses, using the best science available, are necessary—but crucially, not in themselves sufficient. Further insights and policy innovations need to be developed and explored in practice. As Michael Power has argued, there is now an overwhelming tendency in political and organizational life to reach for the "risk management of everything" (Power 2004). However, when faced with potentially disruptive innovations, the danger is that risk assessment—however participatory—merely digs us deeper into the hole from which we are trying to escape. It avoids a much deeper predicament that arises from recognizing the realities of ignorance and ambiguity. Debates that are too often framed in terms only of risk and safety—typically asking the question, "Is it safe?"—imply that the likelihood of certain outcomes, and the question of social commitment, is susceptible to rational calculation. More challenging questions that flow from ignorance concern the longer-term social purposes as well as consequences of a technology's development, and what are the alternatives that might be available?

This concentration on risk is an understandable way of rationalizing an otherwise open and daunting set of questions. It reflects what Zygmunt Bauman describes as modernity's "gardening instinct" (Bauman 1991). Yet this desire to tidy the borders of our democracy means that frameworks of governance and regulation may be stripped of meaningful content. Fundamental questions arise from further examination of today's "global knowledge-economy," perhaps the dominant self-characterization of contemporary society and its established institutions (de Sousa Santos 2003). What kinds of cultural conflict are now emerging centered on the production of scientific knowledge? Are there forms of politics (e.g., new social movements and mass forms of alienated citizenship) that call for new forms of governance of science and technology as the major forces shaping human worlds? What new institutional and organizational forms may be appropriate to articulate these inchoate, globally-distributed concerns, conflicts, and democratic aspirations?

From these wider perspectives, conventional discourses of regulation, risk, and ethics look increasingly inadequate. New government commitments to "upstream" public dialogue with science—if taken seriously—may run rapidly into head-to-head conflict with concerns about global competitiveness and the economic potential of national science systems competing aggressively for global investment and trained personnel. These issues may be difficult to address in a purely national context, especially when public concerns do not correspond with those assumed by scientific, industrial, and policy-making elites (Grove-White et al. 1997; Marris et al. 2001).

In the case of nanotechnologies, the contours of public concern are not restricted to the risks of nanoparticle toxicity. There are other fundamental questions that need to be asked: *Why these technologies? Why not others? Who needs them, and what human purposes are driving them? Under what conditions will they be enacted; and who sets those conditions? Who is controlling them? Who benefits from them? What contingency plans might there be to contain unanticipated disasters? Can those in charge be trusted?* Drawing on the lessons from genetic modification and other controversies, programs of research need to explore how governance and regulation can be extended to incorporate a wider set of cultural and social, and indeed technical, factors (Kearnes et al., forthcoming).

IV. Globalization. Fourth, we need to examine the emerging patterns of nanotechnological innovation worldwide, and what social and governance challenges these pose both globally and for nation-states.

Research is required to map the shifting geographies of nanotechnological innovation and knowledge production. As nanotechnologies start to play a more significant role in the global knowledge economy, what new opportunities for wealth creation will they create? How will they contribute to shifts in the global distribution of knowledge, resources, and power? What forms will these take? Might they allow developing nations to “leapfrog” into a new technological paradigm? Or might they reinforce inadvertent forms of epistemic exclusion, stratified industrialized knowledge-economy divisions of international labor, and new forms of public alienation (Castells 1996)? How will such governance challenges play out across different geopolitical and knowledge sectors?

It is important to understand how the global development of nanotechnologies will be shaped by the relationship between the different temporalities of technological innovation, regulation, and societal deliberation (Jessop 2000). Increasingly, risk discourses are intervening intensely in the very process of product innovation, shaping the direction of entire industries in ways that are not easily anticipated. Nanotechnologies are emerging in a situation of “risk sensitization,” which creates tensions between cycles of innovation and capital accumulation, and the need for governments and industries to respond to public anxieties about possible hazards. Regulation, product testing, and more expansive modes of public engagement and dialogue slow down the process of entry to the marketplace, which may sit in tension with the need for rapid investment return.

Conventional characterizations suggest that precaution acts as a barrier to innovation. In a European context, several recent studies have shown that this is not necessarily the case, and precautionary approaches can, in fact, act as a stimulus for new forms of innovation (European Environment Agency 2001). However, it remains an empirical question as to how such interactions will play out on a global scale. Regulation may slow down the product cycle, or it may provide advantages to some economic actors, possibly favoring larger corporations over smaller start-ups. It may reinforce the economic power of the United States and other leading nations, or enable new, niche players to emerge (as for example, Finland became a surprisingly successful player in mobile communications technologies). In any case, the escalating stakes of managing the public acceptance of scientific innovations in the interests of keeping competitive in the global knowledge economy have brought newly emergent pressures and expectations on the social sciences as policy actors. Our scholarly communities will have to respond constructively and responsibly to such pressures; our proposals attempt to do this, in part, by trying to step ahead of those pressures, and by suggesting other opportunities and agenda, both for research and for the policy it hopes to enlighten.

To summarize, a political-economy social science agenda might embrace the following questions: Where is nanotechnological R&D being carried out and by which kinds of institutions? What factors shape, accelerate, or impede national and international innovation trajectories? What is the impact of emerging regulatory and governance (including civil society) processes on R&D and product development? And how are these dynamics directly or indirectly influencing the substantive intellectual contents and cultures of nanoscientific knowledge?

V. Emergence. Finally, we need to develop new frameworks of theoretical reflection to understand the emergence of nanotechnologies, and, in particular, to develop approaches that move beyond conceptualizing the future in terms of prediction or control.

In moving from a predictive to a postpredictive paradigm, social science needs to develop a set of theories and methodologies for relating to the complexities of multiple “futures” (Grove-White et al. 1997; Prigogine 1997; Sarewitz et al. 2000; Urry 2003; Wilsdon and Willis 2004). The central notion here is that nanotechnologies are a set of dynamic and potentially unbounded systems. Science and technology as cultural forms are the ultimate objects of interest, however precisely these might be defined in all their variety. They develop collective patterns and non-linear consequences not present within their individual components. Such systems demonstrate both the “end of certainty” and long-term irreversibilities, as well as heterogeneity and emergence, as they become locked in to certain path dependencies (Prigogine 1997; Rip and Kemp 1998).

In exploring the nature of technological emergence, the goal is to understand the complex role that these systems and their different temporalities play (Adam 1998). A number of social scientists have analyzed the role of *expectation*, or future-oriented imaginaries, in emerging technologies (see, for example, Brown 2003; Brown and Michael 2003; Brown, Rappert, and Webster 2000; van Lente 1993; van Lente and Rip 1998). Such analyses are fundamentally about future promises, and their epistemic and ontological dimensions. They suggest that the emergence of new technologies is characterized by complex and heterogeneous cycles of hope, expectation, hype, and disappointment, which are connected with material realities. Understanding the heterogeneous time horizons and expectation dynamics embedded within new technological domains is crucial to how new technologies may materialize and become "stabilized" as a transportable "actor network."

Twenty years ago, the philosopher Hans Jonas warned that "Modern technology has introduced actions of such novel scale, objects and consequences that the framework of former ethics can no longer contain them" (Jonas 1984, 34). At the time, he had in mind the awesome transformations wrought by nuclear and genetic technologies. But his analysis can be applied with equal force to the changes that now are underway at the nanoscale. The questions that Jonas posed can be posed afresh today. If these technologies enable human interventions at a novel scale—the very atoms and molecules that are the building blocks of matter—does this require an equivalent shift in the scale of our ethical and sociological imagination?

Conclusion

This article has sought to outline a prospective social science agenda on nanotechnologies as a particular means to further develop a social science of science, technology, and society relations. Such a program of research promises to develop wider social learning and insight on questions of emerging technologies more generally, and on the ways in which social and ethical considerations can be built into the technical and scientific agendas at an early stage. A program of research of this kind promises to build capacity in the social sciences in at least three distinct ways.

First, it will do so locally by drawing upon, extending, and connecting theoretical insights in social theory, postmodernism, actor-network theory, science-and-technology studies, and complexity. Second, it will significantly advance the theory and practice of interdisciplinarity as it applies to collaboration between social sciences, humanities, natural sciences, and engineering disciplines. Third, it will develop a social science that engages with and contributes to policy debates in "real time." Both these latter capacity developments involve more than intellectual developments in themselves. They also involve new knowledge-producing relationships and professional responsibilities, with respect to both the natural sciences and policy practices. Potentially this would involve social sciences becoming, modestly, actors in those worlds and not only observers and commentators of them.

Such an enhanced capability would enable the social sciences to play a strategic role in providing the social research and analysis necessary for the future governance, regulation, and public appraisal of emerging nanosciences and technologies. By clarifying the differential social values and implications embedded within prospective nanotechnology developments, such a program would contribute actively to society's resources for more intelligent and more humanly—as well as technically—robust debate and practice in such matters.

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