Science and Public Policy **41** (2014) pp. 507–519
Advance Access published on 17 October 2013
doi:10.1093/scipol/sct074

Synthetic biology, water industry and the performance of an innovation barrier

Susan Molyneux-Hodgson[1,*] and Andrew S. Balmer[2]

[1]*Department of Sociological Studies, University of Sheffield, Elmfield Building, Northumberland Road, Sheffield S10 2TU, UK.*
[2]*Arthur Lewis Building, Floor 3, Quad A, School of Social Sciences, University of Manchester, Manchester, M13 9PL, UK.*
**Corresponding author. Email: s.hodgson@shef.ac.uk.*

This paper analyses the performance of a research programme that sought to address issues of innovation in the water industry through the application of synthetic biology approaches to water problems. We use this analysis to re-imagine the problem of innovation in the UK water sector. Using textual, observational and interview data, we examine how a series of discourses have, over time, become firmly connected in the context of water innovation. Discourses include: conceptualisation of public actors as consumers who are ignorant of the complexities of water and its true value; and the primacy of market-based mechanisms to produce innovation. We show how these discourses shaped the expectations of academic and industry actors as they sought to use synthetic biology as a solution to industrial problems. Expecting innovation barriers of a certain form, these actors helped to construct the very thing they sought to dismantle.

Keywords: sociology of synthetic biology; ethnography; water governance; water consumers.

1. Introduction

Innovation and governance in the water sector is a topic that excites much discussion across a range of disciplines and involves many public actors. In the UK, alternating drought orders and large flooding events, alongside increased demands on supply due to an expansion in housing provision, have resulted in a number of commissions and reports on water security. A UK Environment Agency (EA) analysis (EA 2012) showed that in the single year of 2012, one in five days in the UK involved a flooding event and one in four days were officially in drought. In 2012, over 20 million people were affected by a hosepipe ban imposed by water companies, followed a few months later by the EA needing to issue over 6,000 flood warnings (ibid). Local water sector concerns about leakage and metering, for example, take on increased importance in response to changing fears around the frequency of flood and drought. In this broad context the search for solutions to all these water challenges is gaining urgency.

Academic scientists and engineers are regularly awarded funding by the UK Research Councils (RCUK), and the water sector itself, to generate solutions or innovations for the industry. Often, these solutions would not fall into the category of 'high-tech', however, the emerging technoscience of 'synthetic biology' certainly does. This field is consolidating around the will to:

> ... design and engineer biologically based parts, novel devices and systems as well as redesign existing, natural biological systems. (Royal Academy of Engineering 2009: 6)

The proponents of synthetic biology (SB) have boldly promised a new industrial revolution and often discuss the promise of the field in relation to the 'grand challenges' that currently face global society (Molyneux-Hodgson and Meyer 2009), most notably fuel scarcity and climate change.

The emergence of SB led two groups of academics—one focused around water engineering and the other around SB—to come together to explore what SB might offer to the water industry and to the future pressures posed by a changing world. A programme of work was funded by the

UK-based Engineering and Physical Sciences Research Council (EPSRC) and was intended to test out novel interdisciplinary research that might otherwise go unfunded. Though the work had specified two particular problems for exploration the remit was quite broad, and as such the technologies to be investigated remained open and under discussion for much of the funding period. The idea was that, as the project progressed, the academic team would negotiate their ideas in relation to industrial concerns. Thus the organisation of the work had an innovative dimension: it involved regular meetings with industrial actors through 'industry days' at which ideas were to be debated in order to educate the industry about the potential of SB and to see how far the industrial actors might be willing to accept that SB approaches could solve some of their problems.

The need to 'transfer' knowledge from academia to industry; and also for academics to demonstrate 'impact', are imperatives under which academia currently labours. To meet such demands the programme embraced a flexible scheme of research that was far more open to non-academic involvement from the start. Indeed, particular funding streams have been developed by RCUK as part of an explicit attempt to mitigate problems with the translation of academic knowledge into industrial products. However, the dominant discourse at the start of the programme remained one of a 'linear' innovation process. As sociologists within the programme we were expected to examine 'the innovation barrier' and help navigate the terrain between academia and industry, a space often labelled the 'valley of death' (Ford et al. 2007; Willetts 2013). The 'valley' between academic innovation and industrial application is believed to inhibit competitiveness and growth in the UK and is seen as a key problem for the water sector in dealing with climate change and other pressing problems. This points towards the continued durability of linear-based models of innovation (Tait and Williams 1999) and can also be understood in terms of broader moves to Mode 2 knowledge production (Gibbons et al. 1994), for example through the inclusion in the project of inter-disciplinarity and industry stakeholders in order to gain funding.

In this paper we report on the sociological work we conducted with colleagues in SB and water engineering as they sought to make SB a solution to water industry problems. We explore how our academic and industry colleagues conceived of 'a barrier to innovation' and how water governance continues to adopt certain notions regarding water users as consumers and of consumers' ignorance. We consider their discourses on publics, governance and research and how these mutually reinforcing constructions served to shape colleagues' expectations and ultimately their research practices. We thus explore how even in research that sought to confront an expected barrier to innovation, by engaging industrial actors throughout a project, naïve models of interaction and assumed linear relations between actors proved to be widespread and persistent. We suggest that the discourses of barriers to innovation became performative of the problem that they had been mobilised to dismantle.

2. Study context and methods

Scholars of innovation have long lamented the dominance of the 'linear model', which conceptualises innovations as emerging from research, proceeding through development and production, before finally being marketed to consumers (Kline 1985). The model has been shown to be unacceptably simple. This is most easily demonstrated by the observation that the drivers of innovation are rarely contained solely within basic research. Indeed, a range of forces act upon innovation processes, not least market, consumer and design forces that are used to justify and enact a range of R&D initiatives. Since the 'linear model' has proven inadequate for innovation studies, a number of alternatives have been proposed, such as the well-known 'chain-linked' model (Kline 1985). Attention has also been directed towards more 'open innovation' models, which highlight:

> ... that valuable ideas can come from inside or outside the company and can go to market from inside or outside the company as well. (Chesbrough 2006: 2)

Moreover, scholars of science and innovation governance have long been concerned with the ways in which such processes are regulated and how democratic oversight of government-funded research is managed and implemented. They have similarly combated notions of linearity, through which 'the public' is conceptualised as an end-user to be consulted on the implementation of technological innovations. Instead, that work has highlighted the ways in which public actors make sense of technical information within context, for example by reference to their social relations to experts (Wynne 1992). Concurrently, they have shown how the notion of 'downstream' public 'end-user' engagement is practically entangled with the conceptualisation of the public as having a knowledge deficit, which excludes public actors from expertise and thus affirms the notion of a unidirectional flow of knowledge from academic and industrial spaces downstream to its consumers. As such, conceptions of public actors as simply ignorant of science and innovation have been firmly challenged, for example in the context of genetic modification (Marris 2001).

In both of these trajectories of scholarship the maintenance of a 'closed' system of innovation and governance is often opposed in favour of a more 'open' system, through which:

> Linear, scientistic conceptions of innovation are [seen to be] giving ground to more plural, socially situated understandings. (Stirling 2008)

At the level of governance of innovation, the acknowledgement of the limitations of the linear model have resulted in the development of what Tait and Williams (1999) have termed a 'linear-plus' model. The hope has thus been for a more democratic notion of 'openness' to prevail, whereby many and varied voices are heard in the shaping of the R&D of technological innovations. Indeed, a range of novel mechanisms for engaging various publics in technological innovation emerged from around the early 1990s (Marris and Rose 2010) that have sought to produce more 'upstream' (Wilsden and Willis 2004) shaping of R&D processes, for example in the development of 'constructive technology assessment' (Schot and Rip 1997).

This work has had some impact in the activities of research agencies and governance processes and SB is no stranger to this confluence of ideas and imperatives. The RCUK has actively sought to learn lessons from what actors in governance and science understand to have been the 'catastrophe' of genetic modification (Marris 2001) and the relatively more successful enterprises within nanotechnology. Within the governance of SB there has been a manifest will to engage publics and social scientists within this 'new' innovation system as it emerges and develops. The major report titled 'Synthetic Biology Dialogue'(Biotechnology and Biological Sciences Research Council, Engineering and Physical Sciences Research Council and Sciencewise (2010), is regularly drawn on by various actors within science and governance in their articulation of how SB is being regulated.[1] For example, they often use this report as evidence that SB is taking public actors' views into consideration and that synthetic biologists are actively interested in how public actors think about SB. In this regard, public actors are regularly conceptualised as being significantly engaged in shaping technoscience. SB, at least in governance discourse, appears to be opening itself up.

Sociological and policy work on SB and its governance has examined how the field's promise to bring engineering epistemology into biotechnology has brought with it a range of debates around industrialisation processes and intellectual property regimes (Calvert 2012; Campos 2012; Hiltgartner 2012). However, this work has not yet adequately examined how innovation with, and governance of SB, is being shaped in local contexts when applied to specific industrial applications. We follow Callon's invocation in relation to economics (Callon 1989) to attend to what innovating with SB does. Our paper responds by observing how our colleagues in SB made sense of public actors and the potential of innovation by using discourses from the context in which they sought to apply SB, namely the water industry.

In examining attempts to bring SB into the water industry we also develop an understanding of how existing discourses within water governance and service provision have been steadily connected into a rather rigid worldview. These discourses have actively sought to make the water industry more competitive (for example during privatisation) and to undo the perceived barrier to innovation that is regularly bemoaned to exist in the water industry (Cave 2009). We argue that these discourses have produced a framework of concepts that strongly influences academic researchers' expectations regarding the potential to innovate in the area of water services and how they imagine the future of SB and the water industry.

Research in the sociology of expectations has shown how promises about the future are made on behalf of technologies that are only in development or do not yet exist. These promises often involve radical transformations of our ability to fight disease, solve environmental problems or revolutionise industries. In this, future visions—whether made by scientists, bioethicists, policymakers or whoever—can, in turn, be used to mobilise current scientific and governance activity in pursuit of those futures (Van Lente and Rip 1998; Brown et al. 2000; Hedgecoe and Martin 2003; Pickersgill 2011).

SB is no stranger to such promises and visions of the future of SB are being actively used to shape current practices of governance and knowledge production. For example, beginning in 2011 a number of meetings were organised between members of the UK Technology Strategy Board (TSB), the Rt. Honorable Vince Cable and the Rt. Honorable David Willetts, plus a few prominent synthetic biologists. This collective of actors seeded the UK Synthetic Biology Roadmap Coordination Group, which produced the SB Roadmap (TSB 2012). As the Roadmap was under preparation, a coordinated, national effort by the TSB SB Special Interest Group aimed to bring potential collaborators together in locations around the country in order to apply for funding. All of this work has been shaped by the expectation that SB will contribute importantly to the future UK economy. Indeed, David Willetts has called SB one of his eight great technologies (Willetts 2013). Moreover, UK funders have acted on the Roadmap by creating calls for a national 'Innovation and Knowledge Centre in Synthetic Biology'[2] and a number of 'Multidisciplinary Research Centres in Synthetic Biology'.[3] The expectation that SB will produce economic gains in the future has clearly been instrumental in shaping current governance practices.

In this regard, the expectations that actors have as regards technological innovations in SB may help to shape those very materials and may thus become performative. As Law and Urry (2004: 393) argue in relation to performative practices:

> . . . we mean that they have effects, they make differences, they enact realities; and they can help bring into being what they also discover.

However, there are ambiguities here, and expectations about the techno-scientific future may not simply produce or be organised around utopian or positive outcomes. Indeed, expectations often involve 'hype',

which might produce disappointment when the realised future is not nearly as transformative as was promised (Brown 2003). Furthermore, expectations of the future might also involve fears, which can bring about changes to governance and research now. The emergence of anticipatory forms of governance and of public dialogues certainly has a relation to such fearful expectations.

In this paper we examine how our colleagues' expectations about governance and public reactions in the context of innovation using SB for water services became performative not so much of their utopian dreams of SB but of their fears that innovation would be stifled. Indeed, their beliefs about the possible future and adoption of extant discourses closed-down a range of possible, bold futures for SB in the water industry, whilst helping to secure research into more incremental improvements in existing techniques. We thus add to the literature on innovation by examining how discourses of governance ostensibly organised to solve a perceived problem of innovation may conversely contribute to the reification of that problem.

We draw on an evidence base of ethnographic work, primarily observational but also involving formal interviews. The latter were semi-structured and the interview schedule developed over time as we engaged with new respondents. We interviewed academic colleagues[4] on the project at its beginning and at the end (totalling 14 interviews), interviewed four R&D managers from water companies in England, and six representatives of the Consumer Council for Water. We also conducted 13 shorter, informal interviews during our observations with a range of academic and industrial actors.[5] For the observational work, we took a multi-sited ethnographic approach (Marcus 1995), visiting a range of industrial, academic and public sites over an 18-month period. We observed the work conducted in industrial and academic facilities and laboratories and participated in public engagement events, meetings, conferences, and 'industry days'. At the same time, we analysed policy documents (produced by a range of institutions), academic papers and books in a range of fields, including microbiology, SB, water engineering and environmental management. Some of these we scrutinised using discourse analysis in order to understand the meanings that structured the arguments. As such, the paper is populated by a range of actors including academics (having engineering, microbiological and sociological interests); employees of water companies; knowledge brokers (Meyer 2010) and a range of institutional and policy players.

In seeking to bring SB into the water industry our synthetic biologist and water engineering colleagues were confronted with, and had (by virtue of their previous engagements with the water industry) already adopted, a series of discourses about publics and innovation that have been constructed in the context of water governance and industry. These discourses from the context of water became important in shaping their vision of the future of SB. In the following sections we examine the construction of these discourses and how they have become linked together in order to later argue that within our colleagues' work on SB they became performative of the innovation barrier that they aimed to dismantle.

3. The water industry and the construction of water users as ignorant consumers

In this section we review some existing scholarship on the water industry to examine some of the competing, yet co-existing, ontologies of water and water users that have become entangled in governance at the UK and EU levels. We then contextualise this scholarship within novel ethnographic data and find that water users are primarily conceptualised as 'consumers' and that this is tied to a certain concept of them as being ignorant of the complexities of water services management.

> In Britain, [the consumer]...emerged in battles over 'necessaries', especially bread and water. Until the turn of the twentieth century, 'consumer' still mainly referred to the person 'using up' water, gas and perishable foods. And it was struggles over these particular taxed consumables (rather than commodity culture in general) that fleshed out a new social and political persona: the consumer. (Trentman and Taylor 2005: 54)

In the middle decades of the 19th century, during Britain's second major cholera epidemic, there was a tension between two competing views of water access: the first having to do with universal needs; and the second having to do with the 'rate paying' citizen. Alongside this, the notion of the consumer as ignorant was manifest: the consumer, for example, was understood to be ignorant of the emerging science of public health and links to water quality (Trentman and Taylor, 2005). Joyce (2003: 69) argues that during this period the 'Chadwickian revolution'[6] also ensured that sanitation became an engineering issue and that the technology and science of sanitation became black-boxed from political and social constitution

Commentators in the decades following this period began to lament the consumer's habituation to free-flowing water and their seeming ignorance of the work that went into the provision of water to the tap. Consumer leagues aimed to create more literate and engaged consumers but were faced by company characterisations of the consumer as wasteful and irresponsible. Efforts to ensure a constant supply thus saw a re-characterisation of the problem from one concerned with poor equipment and infrastructure to one focused on the public's irresponsible use and waste (Trentman and Taylor 2005). By the time the Thatcher government (re)privatised the provision of water, notions of consumption and the consumer were widespread in society. Although other

well-known political transformations had generated the modern version of the consumer, water consumers were positioned as not (only) the ignorant and wasteful water user, but the rational, utility-maximising individual economic actor.

The industry made significant profits upon privatisation in 1989, with a 142% increase in real terms within eight years (Lobina and Hall 2001). Prices rose so much that in the period 1990–5 around 9% of households stopped paying their bills, resulting in legal actions and supply disconnections (Castro 2007). A public outcry ensued. A government review in 1997 forced companies to lower prices and to pay windfall taxes as compensation for non-compliance with mandated infrastructure investment (Castro 2007). The policy of disconnection for late payment was also banned, primarily as a result of pressure from the medical community, in particular the British Medical Association (Castro 2007). As such, a tension was very much present in the regulation of water, specifically between the notion of water as a commodity and water as a right. This conflict between notions of water users as consumers and citizens with rights still continues (Sharp 2006; Westling et al. 2012).

Though the water industry was privatised the neoliberal agenda could not justify full de-regulation. Privatisation thus necessitated the establishment of various agencies to monitor and control the industry (Bakker 2003). Most notable was the Office of Water Services (Ofwat) which was invested with a dual role of ensuring the companies' profitability and representing the public in regulatory decision-making. The simultaneous creation of the customer services committees (renamed WaterVoice in 2002 and now, the Consumer Council for Water) were intended to create transparency and give the public a voice in the regulation of the industry. However, these bodies have brought about a 'professionalisation of participation' in regulatory decision-making—where members become experts in responding to consultation—and concurrently there has been a huge reduction in direct participation by individual citizens (Page and Bakker 2005). This change in public representation in local and national water politics has further invested the governmental regulatory bodies with the power to provide a voice for the public, but that voice has become ever more the voice of the consumer of water and not the citizen (Page and Bakker 2005). One important outcome of this change was the invention of the 'average consumer', whose primary concern is the price of water (Page and Bakker 2005), which is codified within the industry as a concern for efficiency above all else, since this is understood as the main way to lower prices.

Across the binary distinction of rights and consumption, shifts in the conceptualisation of water as an engineering problem have also occurred, notably at the European level: moving from a concern with major pollution events and general sanitation between the 1800s and 1950s, through a focus on point-source emissions and discharge to the environment in the second half of the last century, to the contemporary emphasis on sustainable development and global environmental issues (Molyneux-Hodgson and Smith 2007). The water resources of Europe are increasingly seen as interconnected, driving development of a more holistic European policy for water, the Water Framework Directive (WFD), which came into force in December 2000. The production of this policy reflected an increased concern for the environment, with innovation towards, and payment for, environmental protection at the centre of the governance debate (Kaika 2003). A tension quickly emerged around the development of WFD policy: the need to balance the social role of water as a public good and the increasingly significant role of water as a market commodity (Kaika 2003). A fundamental disagreement between the Environmental Commission of the European Parliament and the Council of Environment Ministers of the EU, meant that a number of compromises were made in terms of policy and language, the most significant being the rejection of the proposal to characterise water as a heritage and not as a commercial product (Kaika 2003). One of the outcomes of the WFD negotiations was a focus on water quality in surface water bodies such as rivers and lakes (Molyneux-Hodgson and Smith 2007) meaning that water services would need to meet new quality criteria (e.g. limiting particular chemicals). This focus on water quality and the shift in emphasis to sustainability worked alongside the acknowledgement that prices would have to increase (Cashman and Ashley 2007). As such, the connection between industrial improvements, innovation and prices became formalised at the European level of governance and—whilst brining the environment more formally into the mix—nonetheless continued to conceptualise water users as consumers primarily concerned with the price of water.

Through all of the above, we can see the interrelationship between industry, governance and notions of publics has been long in the making and thus may be expected to exhibit resistance to change. In our interviews with R&D managers of UK water companies we often found that they articulated the distinction between water as a commodity and water as a right by emphasising the work done in water services. In this regard, they conceptualised water as a product by drawing attention to the expense the industry incurred when treating water and when processing sewage. This helped them conceptualise the water user as a 'consumer' of water:

> A lot of people don't realise how complex it is to collect water, treat it, distribute it and receive waste water from houses, treat it, and discharge it back to the environment. It's very complex, and the challenge is to try and keep customers' bills low. So customers tend to worry about their bills. More and more people [in the company] are taking an interest now, they're trying to be a bit more open and visible and arrange open days and things like that. I think that's the future, to be

> more open and involve the customer. If they know more what they're paying for, then I think we'll end up with a better relationship. (Water company R&D manager No. 1)

However, as we see in this quote, the notion of water as a commodity is not only firmly tied to the notion of the consumer but also to consumers being ignorant of the true value of this commodity. Having concentrated on the notion of water users being consumers of a commodity, the industrial actors then lament the consumer's apparent obsession with price increases. Indeed, the quote articulates the necessary remedy to this situation as public education, reaffirming the notion that the problem is not so much privatisation or a fundamental tension in ontologies of water but rather the consumers' ignorance of how water is treated and what the water companies do for them. This connection between consumer and ignorance is importantly tied to the imagined lived-experience of water users as regards their relation to water. For industrial actors the consumer does not really 'hear' or 'see' water in the right way:

> . . . it's a sort of silent service really, one that's largely taken for granted. The fact that people now pay quite significant bills, I think, has raised the prominence in people's eyes. (Water Company R&D Manager No. 3)

Here, public ignorance is constituted around price, with the water bill understood as the user's primary mode of access to water and to the supply company. As such, industrial actors imagine that this is the consumer's primary means of interpreting the significance of water in their lives. The 'silent service' of water provision is understood to be visible to people only when they are confronted with its financial cost. R&D managers regularly explained public perception of water in this way and thus consolidated notions of water users as consumers whilst then finding ways to explain away their apparent focus on water prices. The result is that other conceptualisations of water users are closed off: users are excluded from expertise and are then blamed for their apparent inability to appreciate the true costs of water. A history of transformations and reconfigurations of water provision has produced an industrial discourse that constructs water users as consumers who are ignorant of water's complexity and value. This becomes importantly tied to the notion of innovation barriers when the discourse meets the governance of water innovation.

4. Water governance, catastrophe narratives and the promise of innovation

In this section we take the influential Cave Review (Cave 2009) on innovation in the water industry as a case study in water governance. We argue that it perpetuated notions of the water consumer as the primary mode for understanding water users and focused on innovation as the solution to all of the major problems facing water service provision, most particularly the pressing issues of global environmental change. The Cave Review immediately cites the industry's accomplishments, framing them as improvements in service and quality, but highlights the 'new challenges' (Cave 2009: 3) that have rapidly come to dominate talk about the future of water: climate change and population growth. These non-local problems are seen to require a 'new way of working' (Cave 2009: 3) that centres on the facilitation of technological innovation. The industry's conservatism is conceptualised as a stumbling block in the development of technological solutions to global problems. The Cave Review locates this conservatism in the economic conditions generated by the industry's privatisation. Since privatisation, the provision of water has been through natural monopoly, meaning that customers requiring water (be they individuals or companies) have little or no choice in their service provider (Cowan 1997). The Cave Review takes this naturalistic monopoly as its problematic and provides a number of recommendations for regulatory and legislative changes to the management of water in the UK, designed to encourage innovation either through competition or collaboration (Cave 2009). These changes to governance include: allowing corporate users to choose suppliers under certain conditions; establishing an R&D body to coordinate action; increasing (monetised) incentives to innovate through improved company performance; and changes to the timescales for measuring performance and the planning for future improvements.

The proposed new modes of governance are framed as being in the service of multiple masters. For a start, the mechanisms are intended to improve innovation, whilst lowering the cost of innovation by improving efficiency. But more than this, the new mode of governance also seeks to benefit: first, the 'average consumer' who cares about price; and secondly, the citizen who, through EU governance, cares about environmental protection and water quality; and finally, vulnerable citizens with low incomes or in non-urban areas. This is summarised neatly in the following quote:

> The Review did not consider competition or innovation as being ends in themselves but a means of improving services for customers, particularly the most vulnerable, and improving environmental outcomes. (Cave 2009: 5)

In this regard, the Cave Review constructs innovation as a solution to a range of problems, from price increases through poverty to environmental change. In doing so it closes off other possible solutions. In part this is because it adopts a notion of the consumer as being primarily concerned with price. Even the concept of 'vulnerability' is dominated by a notion of vulnerability to the costs of water services. Adopting the notion of the water consumer to understand water users helps to shape the types of futures that can be imagined in the governance

discourse. In fact, it focuses on innovation as a process to be promoted with the hope that this will improve efficiency and then solve these problems.

In addition, the Cave Review is dominated by two narratives of potential catastrophe: climate change and overpopulation. In regards to climate change it draws on the EA projections of reduced river flow, wetter winters, drier summers, increased precipitation and groundwater level increases (Cave 2009: 5). Similarly, its predictions for overpopulation come from the Office of National Statistics, from which it presents a projected population increase of 15% by 2030, bringing the total population of England up to 62 million. Significantly, these factors are not uniform. The Cave Review outlines how regions of the UK will be differentially affected, and yet the overall problem is cast in the simple terms of reduced water availability and increased urbanisation, i.e. increased demand and reduced supply. As such, the solution remains the same irrespective of its local variation. Technological innovation is thus again posed as the main driver to solving problems of potential catastrophe.

The Cave Review is a good example of how governance of the water industry, by adopting a limited conception of the consumer, helps to close off possible futures in which water companies and water users change their behaviours in ways that are not directly associated with the price of water, but nonetheless are in the service of solutions for climate problems. They imagine the consumer to be a rational agent motivated primarily by the cost of goods. This is because the notion of the consumer is intimately connected to the notion of choice, and as such with the neoliberal market-oriented mechanism of governing human and corporate behaviour. Pointing towards the way in which sociological scholarship has conceptualised the consumer as a product of advanced liberalism, Trentmann (2010: 1) summarises that:

> . . . since the 1950s [advanced liberal societies] have delegated the mechanisms of rule to the individual, relying on choice and self-monitoring. As people become consumers they cease to be citizens.

As consumers are increasingly organised along principles of consumption there is a decrease in organisation around citizenship. Organising governance of water use around notions of the consumer obfuscates the very many forms of behaviour of which political subjects, as citizens, are capable. Similarly, the Cave Review understands water companies to behave in a similar manner to consumers and to be governable on the basis of market mechanisms that are organised on the basis of financial incentives:

> Introduced in the right way, competition and cooperation between companies, driven by market mechanisms, market-like instruments or regulation can encourage innovation and the delivery of lower prices, a better service and improved environmental outcomes. (Cave 2009: 5)

In our interview data, the national story of regulatory policy tied to global catastrophe is adopted in making sense of everyday work in the industry. One such example is that of leakage, a major problem for UK water companies since it is difficult to detect a leak before it becomes a problem. One of our academic colleagues, intimately connected with the water industry, summarised the importance of innovations in solving the problem of finding leaks:

> Finding leaks? Well . . . Most people take it for granted that they switch the tap on, water comes out, no problem. You only complain about water services when something goes wrong: you turn the tap on and there's a trickle or nothing, or there's a fountain in the road. But the reality is, you know roads, you can see them, and 80% of the same length we've got of distribution pipes, and sewers. But we've buried them, we've put them in the ground, from last week to a hundred years ago, they're all connected together, so trying to find and fix them before they fail, preserve the water, the resources we've got, the energy we've used, keep the costs down, keep the service up, all those things are vital for what we're doing. At the moment we waste between 25% and 30% of the water we treat through leakage that we're not finding, and that's pretty unacceptable in a sustainability context, climate change context. (Water engineer No. 1)

At the beginning of this quote we see the repeated trope of public ignorance: public actors are understood to be ignorant of water until its provision fails and they complain because they do not understand the effort that goes into providing water on a daily basis or the stresses being placed on the system by scale and demand. From there the quote moves to evidencing the complexity of the system, how expansive it is, the difficulty of locating a problem, and of the sheer amount of time that we have been placing stuff underground. Finally there's the efficiency issue, where leaks equal waste. Thus within this quote about a local, street-level issue that manifests to a consumer as a service failure, we find the same discourse around sustainability and climate change come into effect to make the problem far more imperative. In this respect, the everyday problems of water industry practice, such as fixing a burst water pipe, now serve as focal points that connect national, international and global narratives, all of which function to make the meaning of a leak and a dip in household water pressure instantiations of broader sets of meaningful, dangerous situations. By bringing the catastrophe narratives into the discourse of water regulation and service provision, the importance of innovation becomes ever greater. However, the discourse also maintains the image of the consumer as ignorant and as only concerned with price. As such, these two tropes in the discourse help to construct an imagined future in which public actors cannot contribute to changing corporate or individual consumer behaviours. The only possible solution to global problems such as climate change thus becomes radical innovation.

However, the discourse also positions innovation practices in tension with consumers, since public actors are understood to only desire low prices. The connection between these concepts in the discourses places innovation in a bind, in that it requires bolder (more costly) research but must also remain in the service of its consumers, who are ignorant of the value of water and unwilling to pay more for it. As the water industry has been privatised and governance has sought to make it ever more competitive and model it ever more on non-monopolised industries a number of concepts have been mobilised that make innovation the only solution to water industry problems. Concurrently, innovation is held back by constructing consumers as obstinate barriers. In Section 5 we examine how our colleagues in SB and engineering adopted these discourses and concepts in their research practices and how this shaped their expectations about the future of SB innovations.

5. Performativity and industrial conservatism: Making expectations come true

From our initial interviews and observations we quickly established that engineering academics and some industry workers—usually trained as civil engineers—invariably report that water services is 'a conservative business'. Their construction of conservatism fell into three main categories: first, the industry does not take risks; secondly, it is heavily regulated; and thirdly, it is limited by customer's misunderstandings of the reality of water treatment and distribution. This characterisation of the industry was used consistently by participants as an explanation for a perceived lack of technological development, specifically in terms of technology transfer from academia to industry or from the laboratory to the 'real world'. For example, two academic engineers, particularly frustrated with the perceived innovation barrier, explained thus:

> You only have to look at the problems the industry has, of taking on new technologies, of a relatively incremental nature. So, a new way of detecting leakage with noise takes ten years to get to industry. It's a tried and tested technology, they already use it [elsewhere]. It's developed from the same technology, [yet] it takes them ten years to do it! (Academic engineer No. 2)
>
> They don't tend to spend a lot of investment on new, crazy, exciting technologies like the pharmaceutical industry would do. Their core business is providing clean drinking water and if they do that well, then they stay with that. It's not for them to design a new drug or something, so their research and innovation tends to be a little more conservative. It's not driving a new frontier quite as much. (Academic engineer No. 1)

In the first quote the water engineer articulates a recurrent trope in our data, namely the issue of the time taken to implementation. In the example above, even a solution based on existing infrastructure, processes and practices is seen to take a significant period of time to move from the laboratory to widespread industrial use. An explanation for this was given as the scale of the industry and thus the expense of change. Indeed, the idea of the scale of the industry was often connected to the problem of innovation. The companies are simply uninterested in anything that will massively increase their capital expenditure without a clear and direct incremental improvement in their operations. This is precisely because they cannot gain a slew of customers by introducing new products. Instead, to increase profits they can only reduce their costs of service or raise their prices. The project of making SB solutions, on which these actors were working, however, was very much intended to drive a new frontier in the industry—or at least to test out the possibilities for such action. As such, our academic colleagues wanted to understand how they could overcome this problem of conservatism that posed a barrier to their innovations so as to implement SB solutions in the water industry.

Importantly, however, they adopted the same set of concepts that connect consumers to innovation barriers in the set of discourses we analysed above. For example, our colleagues frequently connected the perceived problems of the industry and of funding innovation to the knowledge-deficit model. The subtext of this construction of the consumer was that educating them about the costs of fixing pipes, cleaning water, maintaining reservoirs etc., would result in them accepting higher prices for water, allowing the companies more profit margin and thus producing funding for more research. This is visible in the quote from an R&D manager below and then mirrored in the academic quote that follows:

> The customer isn't willing to pay. We'd have to triple or quadruple the bills [if we innovate]... The regulator funds us to keep things in service... the only thing we can do is to patch them up. (Water company R&D manager No. 4)
>
> Interviewer: And why do we only replace such a small percentage of the pipes?
>
> Again, it's about the value of it. The cost the consumer is willing to pay. There are various consumer councils for water... that do willingness to pay surveys of customers, buying water surveys, from a customer perspective, and the values they keep coming back with are shockingly low in this country... So we still don't value it or worry about that resource as a society. (Academic engineer No. 2)
>
> Interviewer: What do you think the explanation is?
>
> Our social perception of water, how we value it, how we think about it from day one. The easy contrast is Australia. The inside cover of every newspaper has got [measures of] what levels the reservoirs are [at], what the water resources are, they're taught from day one in schools and education what a valuable and important resource water is. (Academic engineer No. 2)

In this discourse public ignorance leads to a perceived inability of the water sector to innovate as the public would not be willing to pay the 'true' cost of innovation or improvement to the systems. Hence our actors' accounts privilege education about the value of water as being the main way to improve innovation potential.

Similarly, the shared beliefs about consumer ignorance and fear permeated the organisation of the research project. Before the grant was assembled, various researchers at the participating universities met to discuss the potential applications for SB in water engineering. They identified a range of problems facing the provision of water internationally and narrowed these down to just two ideas. When describing their involvement in these early meetings one interviewee put it thus:

> The water industry is quite conservative and now you're layering on top of that concerns of regulators and the public, and in terms of looking at synthetic biology, it is very academically interesting and exciting, but realistically there's never going to be the chance that any of this was going to be used in the water industry. (Academic engineer No. 4)

Thus, prior to putting the grant together the team had already imagined that SB would be far too adventurous and the industry far too conservative for the technology to be used, except in the most controlled spaces. In the end, the team chose to pursue two projects that were structured by how they imagined regulators and the general public would respond. The first project was to be a low-risk and easily accepted technology: pathogen detection. This would provide an incremental improvement in existing techniques by speeding up the process of identifying pathogens in water. The second project was to be a high-risk and more controversial technology: pipe-smoothing. In this, they imagined that the public would be scared of genetically engineered bacteria in drinking water pipes but, because the grant stream they applied to demanded adventurous research, they pursued the idea nonetheless. As such, the application aimed to test out the possible reactions of public and governance actors to the use of SB in the water industry by giving them what our colleagues understood to be two poles of potential, one application that would likely be acceptable and one that would likely not. Moreover, these choices were already embedded in extant discourse relating to innovation, water industry conservatism and climate change. For example, both of these projects were chosen over a range of other possibilities because they had immediate connections to low-cost implementation, improvements in efficiency and to fears around climate. This clearly appeared in the grant application:

> The use of capital investment at a relatively small number of locations [as is currently done to alleviate flood risk] is also unlikely to address the potential impact of climate change on more widespread sewer failures. The work proposed in Theme 2 [of pipe-smoothing] will demonstrate the feasibility of a technique to improve the performance of pipe networks, and if successful, would have the potential to reduce flood risk in a wide area. If this technique could be deployed without significant capital infrastructure costs then flood risk could be reduced within a system at reasonable cost ... Water companies can be risk adverse, often if a poor public reaction is expected, and if the regulators are not supportive.

The sociotechnical work packages were funded and the research began. The immediate focus was on pathogen detection and almost all scientific efforts went in this direction for the first 12 months of the 18 months of activity. However, as the project progressed, meetings were convened to design an experiment to test out the bacteria that might help coat the pipes of the sewerage network and reduce flood risk. This began the work on Theme 2. In these meetings the academic engineers regularly drew on their understandings of the connections between innovation, governance, public ignorance and consumption. For example, in deciding on the context for their experiments (which would, for example, significantly alter the types of bacteria they would be working with) they steered clear of drinking water systems because:

> Negative public perception of using GMOs in drinking water applications would be very hard to overcome.

Instead, they focused on dirty water pipes, which take water away from sewerage systems and return it to the water treatment facility. As such, our colleagues had to choose different kinds of bacteria that were appropriate to the particular types of pipes they envisaged working with and thus the anticipation of public fears became embedded in the research practices of the group and in the material manifestation of their experimental assemblages.

In another example, during a meeting with the industrial representatives, in which our academic colleagues worked with R&D managers to scope out the potential applications of SB, the issue of public acceptability became acute. Actors from industry were brought into the university and engaged in a dialogue about bold, blue-sky ideas for how SB might be used in water services provision. One of the most significant purposes of the meeting had been to imagine what barriers to innovation might exist with each of the many proposed SB technologies. This was done in order to explore how industrial actors felt about the current goals that the project was pursuing so as to see if it might be wise to change those two chosen projects. The blue-sky thinking was also done to scope interest from R&D managers for future research bids. The many and varied ideas that were put forward for potential applications of SB were thus closely examined for potential barriers. The barriers imagined for each technology emerged from discussions between the academics and the industrialists. Because the academics were by now well-versed in the discourse they regularly made use of the link between industrial conservatism, public fears and

ignorance. They brought these connections into the talk about possible innovation barriers. In part, this was to demonstrate that they understood the constraints the R&D managers worked within and to help consolidate their links to these important industrial representatives. However, the R&D managers themselves, whilst aware of these issues and certainly part of the extant discourse, also enjoyed the more 'blue-sky' thinking and were excited by the wide prospects of SB. They came up with a range of fanciful ideas for how bacteria could be used in the context of water, which, of course, often invoked the discourse around innovation and climate change. Nonetheless, one of the major findings in the report that our colleagues wrote about the meeting was that:

> Public [actors] don't realise the extent of the climatic and water scarcity problem to accept radical solutions to the current ways of water provision, as well as having an element of technophobia.

But this was exactly what our colleagues had imagined when designing the project, it is what they talked about in designing their experiments, and it is what they talked about in the meetings with industrial representatives. This was not a finding, it was the consolidation of a future imaginary in the present and whilst they had set out to test the waters for SB they were themselves instrumental in producing the very outcome of conservatism they had sought to avoid.

Thus, all this talk of consumers, ignorance and innovation barriers is not secondary to the action of the project but is importantly entwined with it: it is action itself. The talk helps to make manifest the conservatism of the industry by shaping the academics' work, the research, the experiments, the materials used to make the technology, the ways the technology is envisaged and the ways in which the academics and industrialists relate. For example, the post-workshop report also highlighted that:

> The water industry is risk averse due to its environmental and public health obligations which may deter the implementation of technologically radical solutions like SB.

But again, this is what the project was designed to investigate and to find alternative ways of thinking about. To explore how the academic actors might work together with industrialists to find ways of doing innovative, radical research. But at every step the actors' adoption of the established discourse was recycled, parroted back to each other and re-embedded into their decisions, activities and talk, both as a marker of their expertise and understanding of the industry but also as the discourse that shaped the outcomes of the workshop. The culmination of this major meeting with the R&D managers was a vote on which technologies to pursue. It was no surprise, given this performative nature of their expectations that the two technologies chosen to pursue were the two projects that had originally been determined to be most viable, with the important corrective to the pipe-smoothing being to focus on sewerage pipes and not drinking water pipes.

The extant discourse of water governance served as the framing for the investigation into the possible role of SB in solving water services problems. Indeed, in an interview we discussed with one of the leaders on the project the issues they had presented us with regarding the industrial conservatism:

> People view water as a right, clean water as a right. They don't want to pay, as a customer you don't want to pay a lot of money for your water and you certainly don't want anything to be in it that you think might be harmful. So I think that it is, it is actually quite a risky area to move in to. And I think there was a study done, the Royal Society study, where they had the groups together to look at the social implications and everyone was fine with synthetic biology until you started talking about it in the environment, and that's a huge problem with this. (Academic engineer No. 1)
>
> Interviewer: Why do you think that is?
>
> I think 'cause everyone views its uncontrolled, it's uncontained, and clean drinking water is my right, which I don't necessarily agree with, and if you put something in it to, in an uncontrolled, uncontained way, then it's going to turn into the big monster, I think that's part of the problem. (Academic engineer No. 1)

Here we clearly see that the discourse has been adopted by R&D managers and academic researchers alike. The problem is that this established discourse of conceptual connections has implicitly accepted a linear model of innovation in which consumers are positioned as an innovation barrier. Knowledge cannot be made that is innovative because the industry will not pay for research and will not take risks; they will not pay because the consumer will not pay higher bills; they will not take risks because of regulations and because the consumer is only interested in price; the consumer will not pay more because they are ignorant of the complexities of water services and because they do not 'see' water as a valuable commodity; there is a natural monopoly on water and consumers have no choice in supplier and so it is even more invisible to them. Because our academic colleagues and industrial actors have adopted this series of connections in their articulation of water and research, we suggest that any solution to the innovation barrier will elude them as they use these concepts in creating their expectations of the future and performatively help to build barriers to innovation.

6. Conclusions

In this paper we examined a programme of research involving SB and water engineering as various actors sought to make SB a solution to water industry problems. We wanted to explore how notions of an 'innovation barrier' were mobilised within that programme.

We found that water users are firmly constructed as consumers, who are understood to be ignorant of the true value of water and of the complexity of water services. In this, the consumer becomes a barrier to innovation—from both academic and industry angles—since they are only given voice in respect to the price of water but simultaneously required to change that position. Interconnected to this is the resilient conceptualisation of the water industry as conservative as regards innovation, which links to a need to stimulate competition amongst companies in the national natural monopoly. Mechanisms that imitate market structures are understood to be able to force companies to compete, primarily by stimulating innovation that will bring down costs, improve efficiency and allow for larger profits. At the same time, and because consumers are so rigidly conceptualised, such innovation has become the only promise that can be made as regards solving global problems such as water shortages and flood events, compounded further by climate change. Thus, there is an ever increasing need to drive more adventurous innovations. This set of concepts served to frame academic thinking about water innovation as our colleagues sought to make SB, a field rife with promises and hype, fit water industry problems. As such, this discourse shaped academic practices in constructing research designs and became materially embedded within their experimental assemblages and technical objects. To reiterate, the bacterial species to be worked on and the experimental approaches adopted, were shaped in response to existing framings of industry problems and assumptions about the relations between water services and citizens. These framings were reinforced throughout the programme, especially in the regular academia–industry workshops. In this way, the discourses evident in the programme served to reify the barrier to innovation, becoming performative as our actors used their expectations regarding the future of innovation in water to organise their current practices. Rather than 'reducing' the barrier, the programme ensured that it was reinforced.

Alongside a re-imaging of water innovation processes, our case contributes instructively to contemporary scholarship on the governance of SB. It shows how current governance of SB has sought to produce favourable conditions for its emergence and consolidation by organising current practices in line with anticipated economic futures. This fits with extant scholarship on expectations. However, we have also shown how such promises are connected to other conceptions of the future as they are moved into contexts of application, in this case water service provision. The discursive maintenance of an innovation barrier found in the water case, raises the question of how SB may fulfil the expectations being laid out for its other possible applications. We already know that the SB research community is anxious about public response to their work, thus pre-existing framings of publics already exerts influence on SB innovation and governance. This means that imagined futures for SB must be more carefully examined for how they embed certain expectations that might ignore the important discourses that already frame expectations of the future in the contexts in which it seeks application. Contra to SB governance promoting public participation in techno-scientific futures and opening up innovation, the construction of publics is successfully limiting the range of developments.

In sum, we have shown that discourses organised around the dismantling of innovation barriers and the encouragement of more radical innovations actually served to create barriers by performatively shaping actors' behaviours. The entangling of water, innovation, users and research creates a complex that is intractable to simplistic intervention. Perhaps this case identifies an unwitting performativity, but it nonetheless raises challenges to both existing models of innovation and to conceptions of academic–industry–society relations.

Funding

This work was funded by the Engineering and Physical Sciences Research Council [grant number EP/H023488/1].

Acknowledgements

We are extremely grateful to the anonymous reviewers who provided invaluable guidance during the review process. Thanks also to everyone who contributed to the Economic and Social Research Council seminar series on SB and the social sciences.

Notes

1. See <http://www.bbsrc.ac.uk/web/FILES/Reviews/1006-synthetic-biology-dialogue.pdf> accessed April 2013 for the RCUK 'Public Dialogue on Synthetic Biology' report.
2. See <http://www.epsrc.ac.uk/funding/calls/2012/Pages/ikcsyntheticbiology.aspx> accessed April 2013.
3. See <http://www.bbsrc.ac.uk/funding/opportunities/2013/synthetic-biology-research-centres.aspx> accessed August 2013.
4. They comprised: two chemical engineers/synthetic biologists, one environmental engineer, two water engineers, and two microbiologists.
5. They comprised: three industrial environmental engineers, five industrial process engineers, three academic environmental engineers, one modeller and one control engineer.
6. Edwin Chadwick was a social reformer of the 1800s whose legacy is principally the revolution in sanitation. See for instance his arguments <http://www.

victorianweb.org/history/chadwick2.html> accessed August 2013.

References

Bakker, K. J. (2003) *An Uncooperative Commodity: Privatizing Water in England and Wales*. New York: OUP.

Biotechnology and Biological Sciences Research Council, Engineering and Physical Sciences Research Council and Sciencewise. (2010) 'Synthetic Biology Dialogue', <http://bbsrc.ac.uk/society/dialogue/activities/synthetic-biology/findings-recommendations.aspx> accessed 7 June 2013.

Brown, N. (2003) 'Hope against hype: Accountability in biopasts, presents and futures', *Science Studies*, 16/2: 3–21.

——, Rappert, B. and Webster, A. (eds) (2000) *Contested Futures: A Sociology of Prospective Technoscience*. Aldershot, UK: Ashgate.

Callon, M. (ed.) (1989) *The Laws of the Markets*. Oxford, UK: Blackwell.

Calvert, J. (2012) 'Ownership and sharing in synthetic biology: A "diverse ecology" of the open and the proprietary?', *BioSocieties*, 7: 169–87.

Campos, L. (2012) 'The biobrick^{TM} road', *BioSocieties*, 7: 115–39.

Cashman, A. and Ashley, R. (2007) 'The mosquito, the elephant and the House of Lords Water Management Inquiry', *Interdisciplinary Science Reviews*, 32: 283–97.

Castro, J. E. (2007) 'Poverty and citizenship: Sociological perspectives on water services and public-private participation', *Geoforum*, 38: 756–71.

Cave, M. (2009) *Independent Review of Competition and Innovation in Water Markets:* Final report (April), <http://archive.defra.gov.uk/environment/quality/water/industry/cavereview/> accessed June 2013.

Chesborough, H. (2006) 'Open innovation: A new paradigm for understanding industrial innovation'. In: Chesbrough, H., Vanhaverbeke, W. and West, J. (eds) *Open Innovation: Researching a New Paradigm*, pp. 1–12. Oxford, UK: OUP.

Cowan, S. (1994) 'Privatization and regulation of the water industry in England and Wales'. In: Bishop, M. and Kay, J. (eds) *Privatization and Economic Performance*, pp. 112–37. Oxford, UK: OUP.

—— (1997) 'Competition in the water industry', *Oxford Review of Economic Policy*, 13: 83–92.

EA. (2012) 'Review of the 2010-2012 drought and prospects for water resources in 2013', Environment Agency, (2012), <http://www.environment-agency.gov.uk/research/library/publications/131328.aspx> accessed September 2013.

Ford, G. S., Koutsky, T. and Spiwak, L. J. (2007) 'A valley of death in the innovation sequence: An economic investigation', <http://ssrn.com/abstract=1093006> or <http://dx.doi.org/10.2139/ssrn.1093006> accessed April 2013.

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, C. *et al*. (1994) *The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies*. London: Sage.

Hedgecoe, A. and Martin, P. (2003) 'The drugs don't work: Expectations and the shaping of pharmacogenetics', *Social Studies of Science*, 33: 327–64.

Hilgartner, S. (2012) 'Novel constitutions: New regimes of openness in synthetic biology', *BioSocieties*, 7: 188–207.

Joyce, P. (2003) *The Rule of Freedom: Liberalism and the Modern City*. London: Verso.

Kaika, M. (2003) 'The Water Framework Directive: A new directive for a changing social, political and economic European framework', *European Planning Studies*, 11: 299–316.

Kline, S. J. (1985) 'Innovation is not a linear process', *Research Management*, 28(4): 36–45.

Law, J. and Urry, J. (2004) 'Enacting the social', *Economy and Society*, 33: 390–410.

Lobina, E. and Hall, D. (2001) 'UK water privatisation: A briefing'. London: Public Services International Research Unit, <http://www.psiru.org/reports/2001-02-W-UK-over.doc> accessed June 2013.

Marcus, G. E. (1995) 'Ethnography in/of the world system: the emergence of multi-sited ethnography', *Annual Review of Anthropology*, 24: 95–117.

Marris, C. (2001) 'Public views on GMOs: Deconstructing the myths', *EMBO Reports*, 2: 545–8.

—— and Rose, N. (2010) 'Open engagement: Exploring public participation in the biosciences', *PLoS Biol*, 8: e1000549.

Meyer, M. (2010) 'The rise of the knowledge broker', *Science Communication*, 32: 118–27.

Molyneux-Hodgson, S. and Smith, J. W. N. (2007) 'Building a research agenda on water policy: An exploration of the Water Framework Directive as an interdisciplinary problem', *Interdisciplinary Science Reviews*, 32: 187–202.

—— and Meyer, M. (2009) 'Tales of emergence: Synthetic biology as a scientific community in the making', *Biosocieties*, 4: 129–45.

Page, B. and Bakker, K. (2005) 'Water governance and water users in a privatised water industry: Participation in policy-making and in water services provision: A case study of England and Wales', *International Journal of Water*, 3: 38–60.

Pickersgill, M. (2011) 'Connecting neuroscience and law: Anticipatory discourse and the role of sociotechnical imaginaries', *New Genetics and Society*, 30: 27–40.

Royal Academy of Engineering. (2009) 'Synthetic biology: Scope, applications, implications', <http://www.raeng.org.uk/news/publications/list/reports/Synthetic_biology.pdf> accessed June 2013.

Schot, J. and Rip, A. (1997) 'The past and future of constructive technology assessment', *Technological Forecasting and Social Change*, 54: 251–68.

Sharp, L. (2006) 'Water demand management in England and Wales: Constructions of the domestic water user', *Journal of Environmental Planning and Management*, 49: 869–89.

Stirling, A. (2008) '"Opening up" and "closing down": Power, participation, and pluralism in the social appraisal of technology', *Science, Technology and Human Values*, 33: 262–94.

Tait, J. and Williams, R. (1999) 'Linear plus model. Policy approaches to research and development: Foresight, framework and competitiveness', *Science and Public Policy*, 26: 101–12.

Taylor, V. and Trentmann, F. (2007) *Hosepipes, History and a Sustainable Future*, <http://www.historyandpolicy.org/papers/policy-paper-75.html> accessed September 2013.

Trentmann, F. (2010) 'The long history of contemporary consumer society: Chronologies, practices and politics in Modern Europe'. In: Warde, A. (ed.) *Consumption Vol. 2*. London: Sage.

—— and Taylor, V. (2005) 'From users to consumers: Water politics in nineteenth century London'. In: Trentmann, F. (ed.) *The Making of the Consumer: Knowledge, Power and Identity in the Modern World*, pp. 53–79. Oxford, UK: Berg.

TSB. (2012) 'A Synthetic Biology Roadmap for the UK', <http://www.rcuk.ac.uk/documents/publications/SyntheticBiologyRoadmap.pdf> accessed June 2013.

Van Lente, H. and Rip, A. (1998) 'The rise of membrane technology from rhetorics to social reality', *Social Studies of Science*, 28: 221–54.

Westling, E., Sharp, L., Ashley, R. and Tait, S. (2012) 'A framework for adapting to climate change in the water and sanitation sector: The case of Wales', PREPARED report no. 2012.002 for EU FP7. <http://www.prepared-fp7.eu/viewer/file.aspx?fileinfoID=204> accessed September 2013.

Willetts, D. (2013) 'Eight great technologies', <http://www.policyexchange.org.uk/publications/category/item/eight-great-technologies> accessed 7 June 2013.

Wilsdon, J. and Willis, R. (2004) 'See-through science: Why public engagement needs to move upstream'. London: Demos, <http://www.demos.co.uk/publications/paddlingupstream> accessed 27 July 2012.

Wynne, B. (1992) 'Misunderstood misunderstanding: Social identities and public uptake of science', *Public Understanding of Science*, 1: 281–304.