SEWPS

SPRU Electronic Working Paper Series

Paper No. 106

Socio-technological regimes and transition contexts

Frans Berkhout, Adrian Smith and Andy Stirling
(SPRU)

September 2003

SPRU Science and Technology Policy Research

The Freeman Centre, University of Sussex,
Falmer, Brighton BN1 9QE, UK
Tel: +44 (0) 1273 877130
E-mail: f.berkhout@sussex.ac.uk
http://www.sussex.ac.uk/spru/

Socio-technological regimes and transition contexts

SPRU Electronic Working Paper

June 2003

Frans Berkhout, Adrian Smith and Andy Stirling

SPRU – Science & Technology Policy Research
University of Sussex
Brighton BN1 9RF
United Kingdom

SPRU
Science and Technology Policy Research

Contents

Introduction

This paper is concerned with processes of change and transformation in socio-technical regimes – patterns of artefacts, institutions, rules and norms assembled and maintained to perform economic and social activities. The discussion addresses recent theory in understanding the regime transformation process. We argue that this new approach places too much emphasis on the role of technological 'niches' as the principal locus for regime change. Instead, we argue that there are a range of different 'transition contexts' in which regime change can take place.

Niches are protected 'experimental settings' (Rip and Kemp, 1998) where norms and practices are developed which depart from those of an incumbent technological regime. According to niche-based understandings, regime changes begin when practices and norms developed in the niche become adopted more widely. Their influence grows and gathers momentum, until eventually the wider technological regime becomes completely transformed by the technological configurations originally nurtured within the niche. This is an elegant and plausible model, supported by a rich body of empirical evidence. However, there is a danger that attention to this particular mechanism may have inhibited complementary and more multidimensional understandings of regime change. In this essay, we pose the question as to whether there may be a greater plurality of possible transformation pathways. We discuss the possibility of a number of specific alternative contexts and drivers for regime change, with significant implications for both research and policy analysis.

This paper has two objectives: to develop a critique of the niche-based model; and to set out an alternative 'transition contexts' approach to the explanation of regime change processes. We begin by documenting the recent emergence of niche-based ideas of 'transition management' as a means of informing public policy promoting technological change. We discuss the salient characteristics of the niche-based model and identify a number of unresolved conceptual and practical limitations. Whilst the niche-based model has contributed a great deal to our understanding of regime change, we propose that this work now be carried forward through a clearer analysis of the variety of transition contexts underlying regime change. In order to transcend present preoccupations with niche-based processes, we develop, as a heuristic

exercise, a four-fold typology of transition contexts. This suggests certain insights and prompts a series of questions that we hope may contribute to the continuing academic and policy debate about transition management.

Regime shifts and transition management

Why is it so important to understand better the transformation of technological regimes? One answer is rooted in long-standing questions about the public effects of technology beyond the immediate production and use relationship. Policy-makers and other social groups have a history of seeking to control the deleterious effects of new technologies and/or to encourage technologies with wider social benefits (Bauer, 1995). More effective social control of technology has been a constant concern for industrial societies (and even pre-industrial societies - see Leiss, 1990). However, whilst the concerns have been ever-present, the particular ways in which civil society and public bodies have sought to understand and affect technological change has varied over the years, as has the record of success.

There exists a host of reasons why different interest groups within society have sought to influence at a systemic level the direction of technological innovation. Socio-political aspirations such as social equity (Elliot and Elliot, 1976), gender equality (Wajcman, 1996), reduced unemployment (Freeman and Soete, 1987) and nuclear and conventional disarmament (MacKenzie, 1990; Kaldor, 1983) have all at various times in various places been used to justify normative and social influence on technology policy. In the present European context, issues such as social inclusion, ageing, the 'knowledge society', global competitiveness and community enlargement all compete for attention as potential rationales for efforts to *manage* transformations in technological regimes.

However, the most recent efforts at the deliberate social management of technological change lie in the environmental field. Since the advent in the mid 1980's of the concept of 'sustainable development' as an objective in policy-making, political attention to environmental challenges has grown at national, regional and international levels. In few other areas is the two-edged nature of technological development more pronounced, the ambitions more transcendent, and the conflicts more acute.

Policy-driven interest in system innovation mirrors a change in the analytical focus of literature on technology and the environment. In the 1990s, attempts to improve the environmental performance of technologies tended to emphasise processes of innovation associated with individual technologies. The focus tended to be on switches from more polluting to less polluting processes and products. The primary aims were to develop appraisal and valuation techniques that could inform a choice between different technologies, and to understand how switches were being helped or hindered by regulatory, market, political and institutional drivers (e.g. Clayton et al, 1999). This perspective served as a means to promote the development of individual 'cleaner' technologies – such as emissions control, process management and the use of recycled inputs.

But solutions to many regional and global environmental problems such as climate change, groundwater contamination, urban congestion and waste management appear to require deeper changes across technological systems. The response of analysts, including those developing niche-based models, has been to develop understanding of processes of change across interconnected systems of artefacts, institutions, rules and norms. The interest has been to understand how to foster innovation and diffusion of new technological configurations that deliver goods and services with greater environmental efficiency (Berkhout, 2002). More ambitiously, the aim is to transform the structural characteristics of technological regimes so that they are more responsive to environmental signals and ecological principles, reshaping entire trajectories of technological innovation developed within them (van de Poel, 2002).

This focus on transforming whole technological regimes, rather than separately analysing and promoting more environmental technological artefacts or practices has variously been labelled 'regime shift', 'strategic niche management', 'systems innovation' and 'transition management' in the literature (Kemp, Schot and Hoogma, 1998; Kemp and Rotmans, 2001; Kemp, Rip and Schot, 2001; Rotmans, Kemp and van Asselt, 2001). At the heart of this *transition management* project sits the niche-based model of regime transformation. In this model, transition managers support what they hold to be *desirable* technological configurations by promoting protected institutional and market niches in which favoured configurations are supported and allowed to prosper, enabling them either to replace or transform dominant,

unsustainable regimes. Thus experiments within the niche 'seed' processes of transformation within the existing technological regime. So, for example, recommendations are made for creating protected niches that develop car-sharing or low emission bus fleets, using zero emissions technologies, with the aim of learning and building institutional capacity for the wider transformation of the personal transport technological regime along similar lines (Weber et al, 1999, Hoogma et al, 2002).

Much of the academic and policy activity promoting the development of a transition management approach has taken place in the Netherlands (although it draws on conceptual and empirical inputs which are far broader). Here, the conjunction of a sophisticated, but pragmatic interdisciplinary community of practitioners in the field of technology studies, an established tradition of collaborative cross-institutional engagement in innovation systems and a strong national policy agenda prioritising environmental sustainability have provided fertile conditions for the growth of the transition management approach. As a result, transition management is promoted in the Netherlands as a policy alternative to both hands-off, market-driven technological change and to more classical technology policy approaches ('picking winners'). Quite assertive claims are made about the potential utility of the approach:

> '…strategic niche management is not just a useful addition to a spectrum of policy instruments…it may be the only feasible way to transform environmentally unsustainable regimes' (Kemp, Schot and Hoogma, 1998: 191)

Whilst acknowledging the manifest significance and value of the transition management approach, we will examine in the sections that follow, the extent to which such assertions and aspirations are sustained by the present status of the niche-based model of regime transformation.

Socio-technical niches, regimes and landscapes: an analytical or descriptive model?

Drawing on an earlier tradition in the social studies of technology (especially Bijker, Hughes and Pinch, 1987), transition management theorists have developed a sociologically and historically well-informed analysis. They employ a concept of 'technology' much broader than the 'artefact', or even the 'technique', by including the economic, social, cultural and institutional connotations of particular technological configurations (Ellul, 1964; Winner, 1981; Hughes, 1983; Callon, 1987; Bijker, 1995; MacKenzie, 2001). Technologies in this sense are seen as being formed by, and embedded within, particular economic, social, cultural and institutional structures and systems of beliefs. Conversely, technological configurations themselves constitute, order and change the nature of these encompassing structures. An intimate and dynamic process of structuration of technologies and their social context is seen to be at work, confirmed by case studies and examples from the history of technology (Giddens, 1984). In short, technologies are seen as "socially shaped and society shaping" (Hughes, 1987).

However, the transition management project also draws on ideas and analysis from the field of evolutionary and institutional economics. In this tradition, the term 'technology' tends to be used in a somewhat narrower sense (Nelson and Winter, 1977; Dosi, 1982; Freeman, 1994). To emphasise and handle more explicitly the breadth and complexity of the more inclusive notion of technology, transition management theorists have introduced the concept of *socio-technical* configurations (Rip and Kemp, 1998) This is defined to include the social relations (e.g. the interests, values and behaviours of people and organisations) that link, use and make sense of technological artefacts (e.g. tools and machines). The resulting operational mix of 'software' and 'hardware' is encapsulated in the elegant formulation that technologies are 'configurations that work' (Rip and Kemp, 1998: 330).

In order to accommodate the role of human agency on the part of innovators and entrepreneurs producing new knowledge and artefacts, while also doing justice to the ways in which contexts shape and are shaped by novelty, transition management theorists have developed a *multi-level approach*. The socio-technical regime occupies

an intermediate or meso-level position between the micro-level niches and a macro-level 'socio-technical landscape'. This multi-level model has already been influential in a number of ways. It has helped move forward notions of the wider institutional adjustments that are associated with major technical discontinuities. It has drawn continued attention to the importance of the interplay between the macro-level and meso- and micro-level changes in the unfolding of socio-technical change (systems innovation). And it has furnished a rich body of examples to illustrate these accounts, so helping to develop a set of fertile concepts and ideas (socio-technical niches, regimes and landscapes, as well as transition management itself).

Each of the levels is associated with a particular socio-technical arrangement. These are:

- *Niches*: '…protected spaces for the development and use of promising technologies by means of experimentation, with the aim of 1) learning about the desirability of the new technology, and 2) enhancing the further development and the rate of application of the new technology' (Kemp et al, 1998:186)

- *Regimes*: '…the rule set…embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artefacts and persons, ways of defining problems; all of them embedded in institutions and infrastructures' (Rip and Kemp, 1998:340). Analysts suggest regimes can be characterised along seven dimensions: technology; user practices and application domains; symbolic meanings of technology; infrastructures; industry structure; policy; and knowledge (Geels, 2001; Schot, 1998). This is a wide-ranging list.

- *Landscapes*: '…background variables such as the material infrastructure, political culture and coalitions, social values, worldviews and paradigms, the macro economy, demography and the natural environment which channel transition processes and change themselves slowly in an autonomous way' (Kemp and Rotmans, 2001:7)

Configurations *that might work* become 'configurations that work' as they move in a trajectory from the micro-level of niches to the macro-level of landscapes, gradually representing larger assemblages of practices, technologies, skills, ideologies, norms and expectations, imposing larger-scale impacts on their landscapes until they become constitutive and emblematic of them. Throughout this journey the socio-technical configuration becomes better adapted to its context, becomes more stable (technically and in terms of the social relationships that interpenetrate and mediate the technology) and exhibits growing irreversibility.

The predominantly descriptive nature of this approach creates a risk that, by drawing on past examples of socio-technical transformations, and by developing historical narratives of systems change, future transitions come to be treated teleologically. The impression may be given that there is a degree of inevitability about the process whereby tentative, mobile and elastic socio-technical configurations are seen to lead inexorably, through a cumulative sequence of stages, to lasting and increasingly large-scale changes in a socio-technical regime. In practice, very few local configurations developed in niches are successful in seeding regime transformation. Why and how some niches set in motion transformational change at wider scales while others fail should be the focus of research.

There is no doubt that the multi-level notion of regime transformation has helped move forward our understanding of the nature of regime dynamics. It has also generated fruitful debates about the ways in which transitions might be managed through deliberative processes. This said, there remain a number of unresolved difficulties with the model and the metaphors of change that it employs. In particular, the niche-based model of regime transition appears to represent a special case that does not do justice to all the conditions under which regime change may occur. An analysis that sought to describe underlying processes of regime change in different contexts is likely to provide a firmer grounding for policy action.

The remaining sections suggest ways of developing a more robust analytical framework for understanding change in socio-technical regimes. We argue for consideration of a more differentiated notion of transition. In particular, we propose a

taxonomy of four 'ideal types' of transition, as a way of marking out the ways in which regime changes appear to unfold:

1. Endogenous renewal;
2. Re-orientation of trajectories;
3. Emergent transformation; and
4. Purposive transitions.

We argue that not all transitions are alike. Indeed, it may be more correct to say that each transition displays unique characteristics, dynamics and history. A model of transition processes will always be an abstraction of processes of change that are always local and specific, and where chance and agency play an important role. Our taxonomy of four ideal types is intended to provide a heuristic device to begin the work of constructing a more generalised model.

Before discussing the taxonomy, we will address a series of issues that arise from the niche-based transition management research agenda. Taken in turn, these concern:

- inconsistencies in the mapping of conceptual onto empirical levels in socio-technical regimes;
- ambiguities in the relationship between the niche and the wider regime;
- problems in the notion of the guiding vision; and
- the possibility of top-down, as well as bottom-up processes of regime change.

Conceptual levels applied to empirical levels

We understand each conceptual level in the socio-technical hierarchy to be increasingly structural and therefore less amenable to exclusive control by particular groups of social actors. Thus the defining characteristic of the socio-technical landscape is that it tends not to be open to unilateral change from actors within single socio-technical regimes (Geels, 2001). Landscape processes operate on a wider scale. However, it is unclear how these different conceptual levels should be applied empirically. By this we mean that a socio-technical regime could be defined at one of several empirical levels.

Take as an example socio-technical change in agriculture. The displacement of DDT by less persistent, less toxic and more targeted pesticides based on innovative biochemical mechanisms was made possible by biotechnology research undertaken as what might be recognised as a niche activity. The substitution of DDT might be labelled a regime shift since it involved changes in regulatory systems, technologies, consumer attitudes and the practices of producers and consumers. However, looked at from the higher empirical level of the arable production or general agricultural regimes, one would hardly call this switching of pesticides a regime shift. Crop production remains as heavily based on chemical inputs, with key structural features of the regime thus relatively undisturbed. Moreover, where the 'high input' agricultural regime is seen to be in competition with an expanding 'organic' agricultural niche, developments in either may transform the relative positions of each (as might developments in the socio-technical landscape).

This example, illustrates the case for greater precision in describing the level of analysis implied by the notion of a socio-technical regime. Other examples might focus on whether a socio-technical regime in the electricity sector might best be understood to lie at the level of the primary fuel (coal, gas, oil or nuclear), or in the general configuration of the power generation and distribution system (whether based around large centralised steam-cycle plant and a high voltage grid, or small-scale distributed micro-generation with local distribution playing a greater role). Such examples suggest that contending notions of the socio-technical regime can typically be nested empirically. What looks like a regime shift at one level may be viewed merely as an incremental change in inputs for a wider regime. Or alternatively, a regime shift at a lower empirical level might be seen as a niche activity with regime transforming potential within a higher-level regime. This theoretical ambiguity brings us back to the way transition management understands transformation mechanisms to flow upwards through a widening stream of changes.

Niche processes of regime transformation

The transition management literature suggests that niche-based experiments can transform regimes by nurturing socio-technical configurations, which grow and displace incumbent regime activities. Determinants of the growth of novel

configurations include the resilience and adaptability of the configurations in relation to the wider context of the incumbent regime, the effectiveness with which they are protected and nurtured within the niche, the intrinsic development potential of the niche, the scope for applying niche technologies in new settings, and the niche's compatibility with the incumbent regime (Weber et al, 1999). Yet the 'regime compatibility' criterion for success implies that niches which are radically divergent from the incumbent regime may struggle to seed transformation successfully. The corollary - that more compatible niches may lead to transformations more readily - raises questions over the degree of change that would constitute a transformation.

Alternatively, Geels (2001) – in a study of the transition from sail ships to steam boats – suggests that elements of a niche can seed transformation by 'linking up' with the incumbent regime. Niche activities (such as steam boats) have broken through when they have successfully linked up with and resolved aspects of the incumbent regime that have come 'under tension' (such as the irregularity of wind-powered passenger ships). Here the determinants of success are not so much the general 'compatibilities' of one configuration with another, but in the efficacy with which the new configuration resolves a 'bottleneck' in the incumbent regime. Given the many uncertainties that may exist over compatibility or the efficacy of a solution to a bottleneck, expectations of performance may be as important as manifest evidence (Basalla, 1988; Schot, 1998). Either way, some component of the niche activity potentially resolves a 'bottleneck' that has hitherto constrained further development of the incumbent regime. The niche-derived solution now pushes regime development along a new trajectory (Geels, 2001).

This kind of 'linking' can occur across the different aspects of a socio-technical regime (Geels, 2001; Schot, 1998). In other words, links may be made with the hardware or software of the technologies themselves, associated user practices or application domains, their symbolic meanings, industry structures, infrastructures or associated bodies of knowledge and policy making. If links are successfully forged between the niche and the wider regime, then a process of 'reconfiguration' may

trigger changes across the regime.[1] However, this process is understood to be 'haphazard and coincidental' (Geels, 2001: 29; Schot, 1998). We still do not have a theory of 'linking' that could help us understand how to harness niches to processes of purposive transition management.

The notion of 'tensions' within particular dimensions of a dominant regime and the identification of corresponding opportunities for linking to niche-based experimental configurations suggests a further, hitherto neglected, line of enquiry. The question is, how do these tensions arise? Geels identifies changes in the socio-technical landscape as the source of important tensions in embedded regimes. Broad economic and demographic change, for example, drove millions to leave Europe for the Americas in the nineteenth and early twentieth centuries, thus increasing demand for passenger shipping. This created a market demand for large-scale passenger transport across the Atlantic that was met by fast and reliable steel steam-powered ships. Causation went in the other direction as well, with lower cost passenger transport making the journey affordable to greater numbers of people.

Today, exploitation of natural resources and environmental services are introducing analogous tensions to many socio-technical regimes, albeit tensions introduced via the negative externalities associated with these regimes. The carbon-intensity of the energy and transport sectors is an example, as is chemicals-intensity of agriculture. These observations imply that certain processes of regime transformation operate in a top-down fashion – acting from the landscape downwards into the regime. The important possibility is raised that 'top down' processes may play a crucial role in generating 'bottom up' opportunities for 'linking'.

Guiding visions

Transition management seeks to direct the widening process of socio-technical change and stabilisation around a new regime. The objective for transition management is to steer bottom-up, niche-to-regime processes of transformation towards a pre-defined goal or 'vision' (Kemp and Rotmans, 2001: 4). This vision might be a low-carbon

[1] In fact, the re-configuration may also involve the old regime retreating into niches of its own. It is ironic that one of the final niches for sail boats was transporting coal to the ports around the world so

energy infrastructure, or a cleaner chemical production-and-use regime based on the principles of industrial ecology, and so on. The point to note is that the starting point for the management process is the articulation of the vision. Niche experiments with novel socio-technical configurations create conditions for learning about the viability of a vision and the pathways towards its realisation. These lessons should then inform and possibly revise the vision. Thus 'strategic niche management' introduces reflection into the transition process. Promising niches are further diffused by active policy intervention. Competencies and new skills are built up. New markets are created and user demand promoted. The position of the new configuration is strengthened and a normatively-desirable transformation of the regime is moved on. At all times, however, the touchstone is the vision - always under review, but always driving the transition management process.

It is at this point that we find a disjuncture between the historically-informed niche-based model of regime transformation and the normative policy aspirations of transition management. The niche-based model is derived from a number of examples in which an over-arching, consensual vision of the future socio-technical regime was largely absent (van de Ven et al, 1989), and certainly in the sense anticipated for transition management. In cases such as the advent of radio communications, television broadcasting, electronic computing, the turbojet in air transport and the gas turbine in the electricity system, the formative 'guiding visions' were typically significantly more modest than the eventual uses and impacts of these technologies (Rosenberg, 1994). Conversely, examples abound of misplaced ambition in guiding visions, such as those associated with the development of successive innovations in space flight, nuclear power in transport propulsion, nuclear explosives in civil engineering, supersonic air transport and satellite-based mobile telephony. Of course, there are also examples of guiding visions which fitted the potential of the configurations in question, as perhaps in the case of the automobile, geo-synchronous satellites and terrestrial mobile telephony, The point is that there appears to be no necessary correlation between the character of a particular guiding vision and the scale of the ambitions that are actually realised. Transition management takes historical observations of key features of successful transitions and calls for ambitious

---

that steam boats would have a ready supply of fuel (Gruebler, 1990). Old technologies often continue

normative visions. Implicit are assumptions that a guiding vision is functional to regime change and that it is possible to identify *ex ante* a vision which may then be followed with real prospects of success. Both components of this assumption are problematic.

Right at the outset, there are serious difficulties in determining whether any given guiding vision is socially viable, or reflects a widely-shared objective that is desirable from the perspective of society as a whole. The transition management literature has developed a picture of an iterative and reflective process, providing for reviews of both guiding visions and the emerging configurations. This involves co-ordination between the contending perspectives of a variety of social actors. However, it remains unclear precisely how it can be ensured that the particular set of actors engaged in the development of any given niche do indeed reflect a new constituency of social interests and opinion.

Although somewhat neglected in the transition management literature itself, the question of how to be more inclusive in the engagement of diverse social actors in the regime innovation process is a central concern of the closely related literature on 'constructive technology assessment' (Rip, 1995; Rip et al, 1996; Schot and Rip, 1997; Grin et al, 1997; Schot, 2001). For all its sophistication, this literature also displays a tendency to treat as unproblematic the feasibility and desirability of aspirations to societal consensus aimed at identifying some determinate 'public interest'.

This is not an abstract or trivial problem. It strikes right at the heart of the normative character and public policy aspirations of the transition management project. And it is more than simply a practical difficulty, concerning the most effective operational means to integrate divergent views. A series of profound challenges are documented in the wider social science and environmental policy literature, concerning the intractability of conditions of ambiguity, indeterminacy and ignorance in the social choice of technology (Wynne, 1992, Stirling, 2003). Managerial aspirations are confounded by the incommensurable dimensions of technological performance,

---

to co-exist alongside the new technologies, although their market-share declines.

strongly divergent sociopolitical interests and perspectives, recursive inter-relationships between the social and evaluative context, and the profound and ever-present exposure to surprise. It is well established in social choice theory that there can under such conditions – in principle – be no definitive way to aggregate divergent social preferences such as to yield a coherent ordering of contending policy options (Arrow, 1963, Bezembinder, 1989). In the main cases of interest involving dominant socio-technological regimes with high political and economic stakes in complex plural societies, not only the process of consensus building, but the very notion of public interest itself is highly problematic.

Unqualified and unproblematised notions of 'societal consensus' or 'public interest' can thus often represent little more than rhetorical resources. Where the underlying assumptions, processes and limitations are not made explicit and examined, such concepts lend themselves to deliberate manipulation by socio-political interests on all sides of any debate on technological change. This blurs the distinction between emergent and historically-contingent processes of regime change, and the normatively-driven concept of transition management. It raises the prospect that the implementation, design – and even the very notion of transition management itself – might simply constitute further political resources and arenas for the interplay of the contending interests embodied in competing socio-technical regimes.

There is not the space here to go into pertinent theories of power, ideologies and interests (for useful introductions, see Lukes, 1974 and Eagleton, 1991). The same is true of the extensive literature concerning the nature and context of effective social deliberation, which is of direct relevance to the transition management project (and constructive technology assessment), but which remains relatively neglected (Habermas, 1996 and Munton, 2003). It is sufficient for present purposes to point out that different socio-political constituencies often disagree profoundly as to the best way forward – not least over transitions in technological regimes. This is particularly true in the context of technology policy for sustainable development, where researchers have noted a vast array of competing definitions and interpretations (Pearce, 1989). To some, this all-things-to-all-people quality is a fundamental weakness in the sustainable development vision: one that makes any realistic hope of sustainable development sheer folly (Beckerman, 1994). To others, including the

present authors, the contested nature of the sustainable development 'vision' can be seen as a strength since it creates debate, necessitates continuing reflection, requires us to sift evidence from rhetoric, emphasising the importance of being explicit about what is being sustained, for whom it is being sustained, how it will be sustained, and why it should be sustained for them (Jacobs, 1999; Dobson, 1998).

Either way, the real value of the notion of the 'guiding vision' in transition management does not lie, as is often implied, in its apparently unproblematic normative policy credentials. Quite the contrary. By focusing on the role of guiding visions, attention is concentrated on the importance of legitimate and effective deliberation and learning, and on the crucial role of providing for plurality, reversibility and sustained dissent. This raises issues concerning the diversity and resilience of wider social commitments to particular technological trajectories and the extent to which these commitments might be withdrawn (Brooks 1985; Wynne, 1992; Stirling, 2003). It is acknowledged in transition management that the building of support and expectations around a vision is a necessary first step in attracting the resources and constituency of interests vital for carving out protective niches (Geels and Smith, 2000). The important lesson is that there is a need to be more reflective, explicit and specific about the role of interests and power in this essential first step in the transition management process.

Analysing regime transformation: bottom-up or top-down?

It is at the meso-level where transition management objectives are most closely targeted: a vision for a new socio-technical regime. The niche-based model deliberately uses the term 'socio-technical regime' in place of the longer-standing term 'technological regime' in order to address more explicitly a wider set of social, political and institutional influences in technical change (Kemp et al, 1998). As has been mentioned, in its original setting of institutional economics, the notion of the 'technological regime' implies a narrower set of cognitive and heuristic norms and procedures at the core of the (engineering and technical) innovation process (Nelson and Winter, 1982). Analysts have studied the way such engineering-based regimes channel innovations along particular trajectories (Sahal, 1981; Dosi, 1988). The concept of socio-technical regime includes these more technical dimensions but embeds them in a wider set of sociological and economic relations. Indeed, like

constructive technology assessment, transition management advocates the involvement in strategic niche management experiments of actors normally excluded from policy decisions about technological developments. Strategic niche management is the 'collective endeavour' of 'state policy-makers, a regulatory agency, local authorities (e.g. a development agency), non-governmental organizations, a citizen group, a private company, an industry organization, a special interest group or an independent individual' (Kemp, Schot and Hoogma, 1998: 188). Issues of widespread socio-technical change (rightly) opens transition management to include a set of actors beyond innovating firms and their immediate locus in suppliers and customers.

As already pointed out, networks of actors from the wider society with an interest in a socio-technical configuration will have differing 'visions' for sustainable development and the changes needed to the morphology of a socio-technical regime. Beyond the general issues already discussed, this presents a rather specific difficulty for the niche-based model. Socially-based demands for more sustainable paths of development, for instance, may arise in specific social niches such as civil society organisations and networks, or protest movements. Yet these are only rarely directly articulated at the micro-level in ways that can be translated into technological innovation. It is even more rare that such direct micro-level articulation yields innovations of a form that would be recognised retrospectively as being decisive in the emergence of a particular technological transition. Instead, social aspirations that are becoming embedded in an institutional order typically first need to engage at the macro-level of the landscape of general opinion, legislation and so on, before they can become effective in seeding a transition. At this macro-level they are more likely to be translated into a form that can be channelled into market and regulatory signals that may in turn influence the emergence and adoption of socio-technical novelty, initially at the micro-level.

In the context of sustainable development, perhaps only the Appropriate or Alternative Technology (AT) social movement has sought a process of change that resonates with the niche-based model. The AT movement is part of the wider environmental movement that advocated its vision for sustainable development through the creation of practical examples on the ground (Willoughby, 1990). The wider membership of the environment movement has tended to engage in more

overtly political action and sought directly to change the higher-level socio-technical landscape of institutions and economic structures. Rather than create sustainable niches from below, environmentalists have lobbied, boycotted, occupied, demonstrated and undertaken 'direct action'. Activists have sought to seed transformations from above (Doherty, 2002; Smith, 2003).

It is important to note that this form of change is different to those identified in the preceding section, which brought regimes into 'tension' more generally. In the latter instance, changes in the landscape are not specifically directed at a particular regime, yet they nevertheless put that regime under some tension and induce change. Thus the changing demographic profile of a society or economic reform can have repercussions for a socio-technical regime without this being the motive for landscape changes. In contrast, more overtly political attempts by social groups to change landscape variables do tend to have one or more regimes in mind as targets while making their demands. Environmental campaigns over waste management are directed toward policy-makers at the macro-level (for example, reforming tax regimes, introducing targets) which campaigners believe will induce changes to socio-technical regimes that include packaging systems, the use of virgin and recycled materials in products, waste collection and resource recovery techniques, and so on.

Engagement by social actors may also be focused directly at the incumbent regimes themselves. Since the 1970s, environmentalists have targeted the nuclear industry as a socio-technical regime in its own right, engaging with all the regime dimensions noted in the transition management literature. Activities have challenged the status of the technology as synonymous with progress (symbolism), the basis for investment founded in energy demand projections (policy), the favoured terms of regulation and financing (industry structure), the credibility of the science underlying the safety case (knowledge) and the viability and legitimacy of associated activities of fuel production and waste management (infrastructures) (Greenpeace, 1990). Indeed, although much of this activity was motivated by the aim of establishing alternative renewable energy technologies on a widespread basis, the main socio-political actors considered their efforts to be more productively targeted at the undermining of the incumbent regime than at the nurturing of its potential successor.

One does not need to agree with these aims in order to appreciate the effectiveness of this kind of strategy on an international scale. Indeed, this is explicitly acknowledged on all sides of the nuclear debate (Patterson, 1985), and is reflected in the subsequent history of policy attention to renewable energy as an alternative 'low carbon' option. In many ways, the nuclear case can be viewed as a paradigmatic exemplar of engagement by social interest groups in socio-technical regime change. Yet numerous similar examples may be found: the deliberate targeting of marine followed by terrestrial toxic waste incineration (as a means to foster the development of 'cleaner technology'); campaigns focussing on chemical-intensive agriculture (as a way to promote organic production); and the use of paper (to promote chlorine-free bleaching and the use of recycled fibres). Niche-focused activities by environmental pressure groups also exist, especially in more recent years. Examples such as the hydrocarbon refrigerator and the promotion of consumer photo-voltaics provide case studies for the transition management literature (van der Poel, 2002). In most cases, however, concerted (and often successful) regime-changing engagement by social actors targeted the incumbent regime, rather than its potential successor. This represents a direct antithesis of the bottom-up niche-based model.

The lesson appears to be that attempts at normatively-driven, purposive socio-technical transitions (i.e. those forms most pertinent to the transition management project) do not follow exclusively the pattern described by the niche-based model, but instead imply much greater attention to macro-level processes (public opinion, government policy, the structure and scope of markets) and their capacity to influence and induce innovations at the micro- and meso-level. Here the landscape is actively seeking to act on and influence the regime, not the other way around.

Such an observation opens up the possibility that transitions will not follow the single path envisaged in the niche-based model. In certain contexts, the bottom-up niche-to-regime transformation may indeed generate a novel way of serving an existing or new social function. Yet in other contexts, it may be changes at the macro-level, in the institutional, economic, political, or cultural settings of the landscape, that drive a transformation from the top-down. Since drivers of change originate from both within and beyond the socio-technical regime it becomes important to understand their

origins and how social actors adapt to such pressures. There emerges a clear need for greater acknowledgement and understanding of different transition contexts.

Where does this critique leave us? Although applauding the achievements gained through the current focus on a niche-based model of regime change, we have raised in the preceding sections a series of concerns over the limits and idiosyncracies of the resulting debate. In particular, we argue that current approaches to descriptive and normative discussions of regime change display what might be summarised as three key characteristics:

- They are *unilinear* in that they tend unduly to emphasise processes of regime change which begin within niches and work up, at the expense of those which directly address the various dimensions of the socio-technical regime or those which operate 'downwards' from general features of the socio-technical landscape.

- They are *univalent* in that they underplay the problematic nature of political intentionality and social choice when faced with multiple perspectives and interests. This leads to a tendency to reify notions of consensus and public interest, neglecting consideration of power and the benefits of strategic properties such as diversity and reversibility.

- They are *unidimensional*, in that they under-discriminate between different transition contexts, such as those associated with drivers for change which are alternatively internal or external to the socio-technical regime, or which differentiate between changes than happen due to historic contingency and those that are the result of the deliberate exercise of agency.

Our proposal is that efforts be made towards constructing understandings of processes of regime change that are more *multilineal*, *multivalent* and *multidimensional* in the above senses. This reveals the importance of recognising the multi-level nature of the nested socio-technical hierarchy running from the niche to the landscape, in that (depending on the perspective and the context) one can identify a continuum of

regimes at successively higher levels of socio-technical aggregation, any one of which might serve as a focus for different kinds of transition management strategy. There exists considerable scope for further research in revealing the nature of the different processes and strategies implied by these different levels of aggregation.

Regime stability and change

Theories of change in technological and socio-technical systems stress the stability and continuity of these systems and the rarity of systems innovations. A range of explanations for processes of technological channelling, path dependence, 'lock in' and 'lock out' have been proposed. Dosi (1988), using the term 'technological paradigm', argued that technological regimes were defined as '...a pattern for solution of selected techno-economic problems based on highly selected principles…' In this analysis the choice of technical problems is defined by prevailing knowledge and problem-solving heurstics that '…restrict the actual combinations in a notional characteristics space to a certain number of prototypical bundles.' Arthur (1989) argued that learning effects and increasing returns to economic scale would lead to a process of technological 'lock in' that would systematically exclude competing and possibly superior (in some dimensions) technologies. David (1985) in his famous, though controversial, example of the QWERTY keyboard argued for three factors leading to path dependency in technological change: technical interrelatedness; economies of scale; and quasi-irreversibility. The first and the last of these relate to the 'switching costs' involved in moving from one technological regime to another. A number of other well-known studies use different cases to make similar arguments (Cowan and Gunby, 1996). Finally, Walker (2000) stresses the importance of embedded institutional, political and economic commitments to a particular technological regime identified with a long-term need (maintaining nuclear fuel cycle capabilities in this case). He argues that this process of institutional 'entrapment' is ubiquitous in large technical systems.

The literature therefore places emphasis on the persistence of change along well-defined pathways. Innovation and novelty are seen as being bounded by working assumptions, institutional commitments and capital endowments inherent to a given regime. Technologies and their institutional context therefore interact to guide change along well-defined channels and form barriers preventing switching to alternative

regimes. As with many 'structural' accounts, the problem with this picture is that it says very little about the conditions under which change occurs, or about the switches that may occur between regimes. Regime shifts or successions clearly have occurred in the past. The horse and cart was replaced by the car as the principal means of passenger mobility, and the telegraph by the telephone. We can expect similar transitions to occur in the future.

In our analysis of regime transformations, we therefore take as axiomatic that all socio-technical regimes face competition from alternatives. While regimes exhibit a high degree of stability and coherence, the lesson of regime change is that they are also dynamic and challenged by alternatives. The stability and path dependency of regimes is therefore relative, and regimes are continually subject to competitive selection pressures exerted by other regimes and by new socio-technical configurations in niches. Often these pressures are weak and incoherent, but at other times they become stronger. Some regimes have the capacity to respond more readily to these selection pressures than others. To give two simple examples, the disposable diaper regimes (competing with the re-usable diaper) has been able to respond to selection pressure on environmental grounds during the last 10 years, while the chemical film regime (Polaroid and Kodak) appears likely, for most applications, eventually to be replaced by digital photography.

This feature of technological regimes we term its 'adaptive capacity'. At a simple level, the adaptive capacity of a regime is related to its capacity: to recognise its vulnerability to competitive threats (frequently a collective task of regime members); and to reduce its vulnerability to perceived threats (through competitive innovation or by influencing the regulatory environment, for instance). The greater the adaptive capacity of the regime, the less will be its vulnerability and the more able will it be to respond successfully to competitive pressure.

Another way of characterising adaptive capacity is with reference to the innovation systems literature in which 'functions' of technological systems are defined (Jacobsson and Johnsson, 2001). Jacobsson and Johnson, in an extensive review of this literature, identified five functions performed by technological systems:

1. *Creation of new knowledge*: the main source of variety in technological systems.[2]
2. *Influence over the direction of search processes among users and suppliers of technology*: the articulation of supply and demand is seen as critical to the perceived costs and benefits of regime switching.
3. *Supply of resources*: These include capital, competences and input materials as well as political resources that support the legitimacy of a regime.
4. *Creation of positive external economies*: This is a pivotal characteristic. An example is the formation of socio-technical networks that provide 'spillover' effects by reducing uncertainty, reducing the cost of information, accessing tacit knowledge and sharing costs.
5. *Formation of markets*: Innovations rarely find ready-made markets, which therefore need to be stimulated or created afresh. Market formation is related to the marketing efforts of firms, as well as the regulatory and other influences on the shape of markets.

More adaptive regimes would be those that are able to perform these functions effectively. Over time, we would normally expect more adaptive regimes to succeed and those with less adaptive capacity to be subsumed or substituted.

Having established that socio-technical regimes face competitive selection pressures to which they must respond and adapt, the next question concerns the source and configuration of the selection pressure. Such competition may emerge in a number of different ways:

- The creation of novel socio-technical configurations for meeting a social function within niches (e.g. the application of membrane technology for municipal wastewater treatment).
- An innovation that seeds a transformation in a higher-level regime (e.g. the impact of high-levels of wind turbine capacity on the structure and operation of the electricity system).

[2] Note that variety is seen as a structural feature of technological systems, rather than something that is generated in response to specific pressures or opportunities.

- The spur to innovation felt through competition from another socio-technical regime serving the same or over-lapping markets or social functions (e.g. competition between the different electricity technological regimes: coal; gas; oil; nuclear; and renewables).
- The competition between different 'visions' for the future held by a variety of social actors, some of whom are more directly embedded within the regime than others; and the different power resources they have to pursue these visions (e.g. current contention over the use of 'science-based' risk assessment versus more broad-based 'precautionary' approaches to chemicals regulation).
- The generation of changes in the socio-technical landscape that put the regime in tension (e.g. liberalisation of energy markets in the EU).
- Politically-motivated change in the landscape targeted at changing a range of problematic socio-technical regimes (e.g. the current public debates and campaigns over genetically-modified foods in the EU).

Looking at this list of competitive pressures, we can draw some general conclusions relevant to research about transition contexts and regime transformations. First, selection pressures act on socio-technical regimes at different levels. The magnitude and form of these pressures and the capacity of the regime to respond to them will have consequences for the pattern and direction of the transformation process. Thus the prevalence of a strong downward pressure deriving from landscape change may tend to drive transformation differently to the growing success and expansion of a niche-based alternative. A bottom-up process may transform the dominant socio-technical configuration, or it may fail to do so; while a top-down process may only prompt incremental changes that relieve tensions in the incumbent socio-technical regime. In other instances, selection pressures may converge - top-down tensions creating opportunities for niches to link into and change the incumbent regime. Moreover, these top-down and bottom-up drivers play out in the context of underpinning economic drivers for firms to remain competitive, maintain or expand market share and profits, provide satisfactory returns to investors, behave as socially-responsible entities and so on. It is shifts in the relative strength of the selection pressures that generates opportunities for change. The art in transition management

must be in recognising which driver offers the best leverage for change at which point.

Second, some selection pressures are consciously and purposefully targeted at regime transformation, while others emerge as it were autonomously and contribute towards change. This distinction between what was intended and what emerged unintended is partly accounted for in the debate about the relative importance of agency and structure in explaining change. To the extent that entrepreneurs and other advocates are always necessary for a new technological configuration to come to life and to be diffused, the changes motivated by innovation are always intended and therefore attributable to agency. But regime transformations are more usually explained as the unintended outcomes of small technical and other adjustments. The Kondratiev-Freeman long-wave theory of technological and institutional transformations is expressed as unintended outcomes of processes that early innovators could not have imagined, let alone guided and managed (Freeman and Louçã, 2001). All transformations include a mixture of the intended and the unintended, but the degree to which they are either one or the other may be a way of differentiating transition contexts.

Transition contexts: the degree of coordination and the locus of resources

In summary, we argue that specific configurations of selection pressures on the socio-technical regime will account for specific, historically-situated transformation processes. Relating the context of transformation to transformation processes must become a starting point for analysis, particularly for transition management advocates seeking the purposive steering of regime change.

As a first step, we suggest that transition contexts can be mapped using two differentiating factors. The first dimension relates to whether change is envisaged and coordinated at the level of the regime, or whether it is the emergent outcome of the normal behaviour of agents within the regime (involving no new mechanisms of

coordination).[3] This dimension seeks to distinguish between regime transformations that are intended and those that are unintended outcomes of historical processes.

The second dimension concerns the degree to which the response to selection pressure is based on resources available within the regime (or which can be co-opted by the regime), or depends on resources that are only available from outside the regime. Relevant resources would be those needed to carry out the regime functions listed above. The *locus* of the resources to recognise vulnerability, and to innovate and adapt is therefore important to the nature of the transformation process. If the resources to adapt are available internally, then change is likely to be more incremental and structural relationships within the regime are less likely to be overturned. If the capacity to adapt is highly constrained by the lack of resources internally then the opportunity for major structural change exists. The *coordination of actors-locus of resources* framework gives rise to a fourfold mapping of transition contexts (see Figure 1).

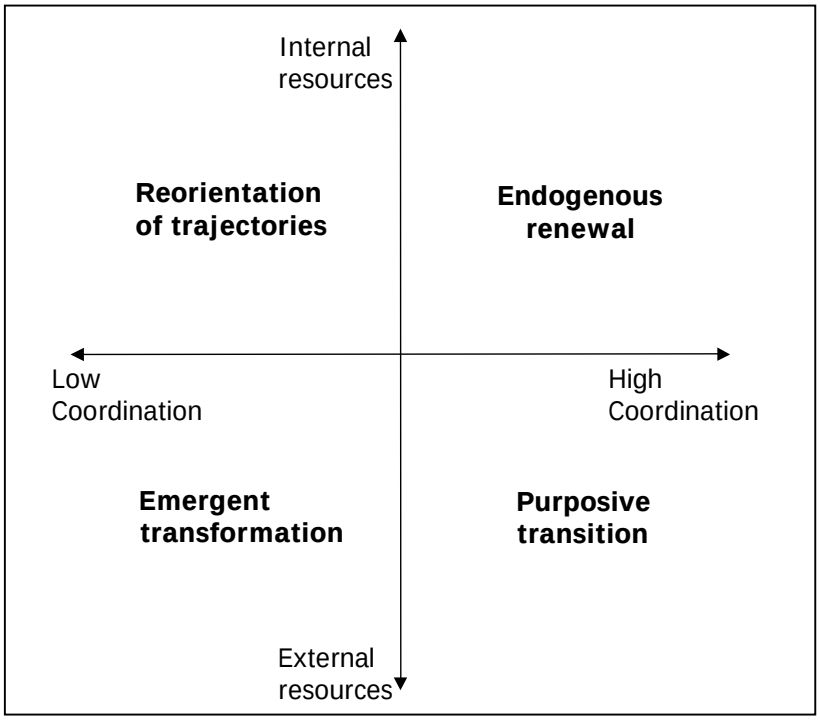

Figure 1: Four transition contexts and transformation processes.

[3] In making this distinction between low and high levels of coordination we want to move beyond a simple planned/market-based dichotomy, to take account of more complex processes of the social

The four quadrants produced in this framework represent schematic 'ideal types'. Comparisons and contrasts between the elements of each transformation can be made against real-world regime transformation processes and our understanding of the variety of processes consequently improved. As has been suggested above, whatever the nature of the selection pressures and the responses to them, the four transition contexts may all play out operationally at different levels of aggregation. This extends from the 'micro level' concept of the niche to successive 'meso level' notions of the regime. Indeed, the nested character of alternative boundary definitions for what is held to constitute a socio-technical regime will vary between contexts and perspectives. This said, the value of the framework as a heuristic device should be clear. It is not the intention to claim any definitive status for the particular scheme we propose here. The idea is rather to illustrate, in principle, the potential for more pluralistic understandings of regime change and to prompt new directions for research. In any event, it seems that this more open-ended framework for the understanding of transition processes may help to test the proposition that there exists a more diverse array of contexts and drivers than those presently highlighted by the niche-based model of regime transformation. In attempting to make more explicit the distinctions between possible transition contexts, we may hope to develop a richer and more robust basis for understanding the different processes of socio-technical transition and the associated opportunities for normative policy intervention.

As a first step towards this aim, each of the transition contexts introduced above are briefly described below. A series of stylised examples – emphasising the energy sector for the purposes of effective comparison – are used to provide more concrete illustration.

1. *Endogenous renewal*

Endogenous renewal arises in the context of socio-technical regime actors, networks and institutions (firms, supply chains, customers, regulators) making conscious efforts to find ways of responding to a perceived competitive threat to the regime. In the terms of our typology, the pressure to change the regime is a result of high

regulation of technologies that involve not just the state, but also other social actors including civil society organisations and consumers.

coordination and responses are based on resources originating within the regime. However, given that innovative activity is shaped from within the regime itself, it will tend to be steered by the prevailing values, cognitive structures and problem-solving routines of the incumbent regime. Decisions over future technological choices will be guided by past experience. Thus the transformation process will tend to be incremental and path-dependant. Looking back over a long period of time the transformation can appear radical, but it will have come about through an alignment of smaller changes.

An example of this kind of process may be found in the progressive scaling up of the thermal capacity of steam-generating plant over the course of the twentieth century. Constituted by a multitude of individually minor organisational and engineering innovations, the result was a radical transformation in the character of the electricity regime (Hughes, 1987). Likewise, investment in flue gas desulphurisation plant as a response to concerns over acid emissions (Boehmer-Christiansen and Skea, 1991), or the development of carbon sequestration techniques might also be taken as examples of endogenous renewal. In either case, the long-term implications, were the processes of change to be deep-seated and sustained, would be one of incremental regime transition.

2. Re-orientation of trajectories

Some socio-technical regimes exhibit an intrinsic property of 'systemness' (Rosenberg, 1994:216-17) in their processes of change while at the same time being highly unpredictable. In these regimes, trajectories of change may be radically altered by internal processes without being associated with discontinuities in the actors, networks and institutions involved in the regime. The stimulus for the radical re-orientation is a shock (from outside the regime or within) impacting upon the technological system. The response, however, is formed within the incumbent regime. In the electricity sector, an example of this kind of regime change might be seen with the advent of wide-scale adoption of combined cycle gas turbines, especially in the UK (Islas, 1997). This radical transformation in the technical and operational characteristics of generation systems was not widely anticipated or intended, but arose through the conjunction of a series of uncoordinated technological opportunities, changes in market regulation and obstacles facing alternatives such as coal and

nuclear generation. However, the adoption of gas turbines was managed within the dominant electricity generation regime, rather than being a development imposed from without.

3. Emergent transformation

Many classical regime transitions have an apparently autonomous (though socially-constructed) logic. This type of transformation in our typology arises from uncoordinated pressures for change and responses formed beyond the incumbent technological regime. The technological cycles described in Kondratiev's long waves have this character of emerging from highly complex social and economic processes that lead to the emergence of technologies with pervasive impacts. Many of the examples used in the technological transitions literature have this form (Christensen, 1997). Their origin is typically in scientific activity often carried out in universities and small firms operating outside existing industries (Dosi, 1988). These transitions can be observed, but there appears very little basis *ex ante* to distinguish between those alternatives that will 'catch on' (Mokyr, 1991:276) and those that will not. In the energy sector, a long term example is provided by the series of 'energy successions' governing the dominance of different 'primary fuels' running over a period of three centuries or so from wood, through coal, to oil and gas. Contemporary examples of these kinds of technologies with major disruptive potential include information technology and genetic-modification technology in the food and pharmaceuticals sectors. The impacts of these technologies have of course been across many different technological regimes – in this sense it is incorrect to speak of a single transition, but of many parallel transitions stimulated from a common technological basis and shaped by regime-specific configurations of interests and goals. It is also clear from the GM example that the environmental impacts (as perceived by key actors and institutions) of these emergent transitions may remain quite uncertain even some way down the process of path creation.

4. Purposive transitions

While emergent transitions have an autonomous quality, we seek to distinguish these from purposive transitions which have in some senses been intended and pursued to reflect the expectations of a broad and effective set of interests, largely located outside the regimes in question. A good example of this type of transition is the history of

civil nuclear power in the industrialised world, and the possible partial transition to the greater use of renewable energy technologies. Nuclear power was widely regarded in the 1950s and 1960s as a critical technology with the potential to generate broad economic and political (military) benefits. A common narrative was developed which involved a series of technological transitions from uranium fuel cycles (with the light water reactor as the main conversion technology) to plutonium fuel cycles (with the fast reactor being the conversion technology). Scientific, policy and industrial interests were co-opted to this vision to form a powerful interest grouping which was typically in strong contention with established interests within the incumbent socio-technical regime of the electricity system itself. This latter example shows that this form of transition – imagined, planned and partially executed – does not necessarily generate social and environmental benefits.

Transition management is the transformation of a socio-technical regime guided primarily by negotiation between social actors from beyond the regime. Key to the transition management project is that these social actors have a greater role in forming the socio-technical response to the co-ordinated pressure for change. Obviously, this demand for change has to be mediated by the regime actors. Transition management is also the outcome of a deliberate attempt to change the regime. Thus, if our schema is accurate, the transformation process is most likely to be that of purposive transition. The historical transformations used to construct the niche-based model of transformation tended to be the result of many contingencies and managed through changes internal to the regime, i.e. emergent transition. Of course, the transition context for any given socio-technical regime need not be fixed. Contexts may change, and the proposition in this paper is that any change in context will influence the pattern of regime transition.

Conclusion: developing a research agenda

In this essay we have sought to illustrate the need to be more explicit and specific about the relationships between contexts and processes of change in socio-technical regimes. We suggest a heuristic and schematic distinction based on the degree of coordination of regime change between actors, networks and institutions, and the locus of resources required to respond to selection pressures acting on the regime. This framework produces four different contexts for regime change, distinguishing

between 'purposive transitions' (deliberate change caused by outside actors), 'endogenous renewal' (deliberate change fostered by regime members), 're-orientation of trajectories' (spontaneous change resulting from relationships and dynamics within a regime) and 'emergent transformations' (the unintended consequence of changes wrought outside prevailing regimes). Taken together, this picture suggests a rich conceptual arena for the interplay of different forms of selection pressure, different configurations of actors, networks and institutions, and different resources to respond to pressures for change, all operating at various levels in the socio-technical continuum.

The typology is a first attempt at a heuristic device based on ideal types. If it has any utility then this will arise through its further application and elaboration. The following are a few research challenges that could constitute such development:

- The notion of selection pressures operating at the level of a socio-technical regime needs to be further elaborated and grounded in theory. Selection pressures are typically thought of as operating at the level of firms and discrete technologies, rather than at the more macro regime level.
- Assessments are needed of regime function (following Jacobsson and Johnson's typology) and of 'adaptive capacity' based on comparative measures, so providing the basis for a more analytical (and less descriptive) approach to regime transitions. Critical to this will be the analysis of the resources that are needed to respond to selection pressures.
- Further elaboration is needed of the ideas of coordination of change and the locus of resources to enable change. Again, approaches and measures for characterising these two dimensions of regime transformations need to be developed, and the conjectures we have made about transition contexts need to be tested.

Research must elaborate the relationships between transition context and regime transformation process sketched out in this essay. A better understanding is needed of the distribution of innovation system functions in socio-technical regimes, and how these can be guided or augmented through public policy.

Acknowledgements

An earlier version of this paper was presented at a workshop on 'Transitions and System Innovations' held at the University of Twente, Enschede, 4-6 July 2002. We acknowledge the comments of workshop participants and are grateful for comments from our colleagues Staffan Jacobsson and Ed Steinmueller. Thanks also to Michelle Harris for chasing up references.

References

Arrow, K. (1963). Social Choice and Individual Values. Yale University Press, New Haven.

Arthur, W. (1989). "Competing technologies, increasing returns and lock-in by historical events." The Economics Journal **99**: 116-131.

Basalla, G. (1988). The Evolution of New Technology. Cambridge University Press, Cambridge.

Bauer, M. (1995). Resistance to New Technology. Cambridge University Press, Cambridge.

Beckerman, W. (1994). "Sustainable development: is it a useful concept?" Environmental Values **3**: 191-209.

Berkhout, F. (2002). "Technological regimes, path dependency and the environment." Global Environmental Change **12**, 1: 1-4.

Bezembinder, T. (1989). "Social choice theory and practice." In C. Vlek and D. Cvetkovitch (eds), Social Decision Methodology for Technological Projects, 21-39. Kluwer, Dordrecht.

Bijker, W. (1995). Of Bicycles, Bakelites and Bulbs. Toward a Theory of Sociotechnical Change. MIT Press, Cambridge, MA.

Bijker, W., T. Hughes and T Pinch (eds.). (1987). The Social Construction of Technological Systems: new directions in the sociology and history of technology. MIT Press, Cambridge MA.

Boehmer-Christiansen, S. and J. Skea (1991). Acid Politics: Environmental and Energy Policies in Britain and Germany. Belhaven Press, London.

Brooks, H. (1985). The typology of surprises in technology, institution, and development. In W. Clark and S. Munn, Sustainable Development of the Biosphere, 131-155. Cambridge University Press, Cambridge.

Callon, M. (1987). "Society in the Making: the study of technological as a tool for sociological analysis". In W. Bijker, T. Hughes and T. Pinch (eds.) The Social Construction of Technological Systems: new directions in the sociology and history of technology, 83-103. MIT Press, Cambridge, MA and London.

Christensen, C. M. (1997). The innovator's dilemma : when new technologies cause great firms to fail. Harvard Business School Press, Boston, MA.

Clayton, A., G. Spinardi, and R. Williams (1999). Policies for Cleaner Technology: a new agenda for government and industry. Earthscan, London.

Cowan, R. and P. Gunby (1996). "Sprayed to death: path dependence, lock-in and pest control strategies." Economic Journal **106**: 521-542.

David, P. A. (1985). "Clio and the economics of QWERTY." American Economic Review **76**: 332-337.

Dobson, A. (1998). Justice and the Environment. Routledge, London.

Doherty, B. (2002). Ideas and Actions in the Green Movement. Routledge, London.

Dosi, G. (1988). "The nature of the innovative process." In G. Dosi, C. Freeman, R. Nelson, G. Silverberg and L. Soete (eds.) Technical Change and Economic Theory, 221-238. Pinter, London.

Dosi, G. (1982). "Technological paradigms and technological trajectories: a suggested interpretation of the determinants and directions of technical change." Research Policy **6**: 147-62.

Eagleton, T. (1991). Ideology: an introduction. Verson, London.

Elliot, D. and R. Elliot (1976). The Control of Technology. Chapman and Hall, London.

Ellul, J. (trans. J. Wilkinson), (1964). The Technological Society. Knopf, New York.

Freeman, C. (1994). "Technical change and technological regimes." In G. Hodgson, W. Samuels and M. Tool (eds.) The Elgar Companion to Institutional and Evolutionary Economics, 309-315. Edward Elgar, Aldershot.

Freeman, C. and F. Louçã (2001). As Time Goes By. Oxford University Press, Oxford.

Freeman, C. and L. Soete (1987). Technical Change and Full Employment. Basil Blackwell, Oxford.

Geels, F. (2001). "Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and case study." Nelson and Winter DRUID Conference, Aalborg, Denmark, June.

Geels, F. and W. Smith (2000). "Failed technology futures: pitfalls and lessons from a historical survey." Futures **32**: 867-885.

Giddens, A. (1984). The Constitution Of Society : outline of the theory of structuration. Polity, Cambridge.

Greenpeace International (1990). Questions and Answers on Nuclear Energy. Greenpeace briefing paper, London, April 1989.

Grin, J., H. van de Graaf and R. Hoppe (1997). Technology Assessment through Interaction: a guide. Rathenau Institute, The Hague

Gruebler, A. (1990). The Rise and Fall of Infrastructures. Physica-Verlag, Heidelberg.

Habermas, J. (1996). "Popular sovereignty as procedure". In J. Habermas, Between Facts and Norms: Contributions to a Discourse Theory of Law and Democracy, 463-90. MIT Press, Cambridge, MA,

Hoogma, R., R. Kemp, J. Schot, and B. Truffer (2002) Experimenting for Sustainable Transport: the approach of strategic niche management. Spno Press, London.

Hughes, T. (1987). "The evolution of large technical systems." In W. Bijker, T. Hughes and T. Pinch (eds.) The Social Construction of Technological Systems: new directions in the sociology and history of technology, 51-82. MIT Press, Cambridge, MA.

Hughes, T. (1983). Networks of Power Electrification in Western Society, 1880-1930. Johns Hopkins University Press, Baltimore.

Islas, J. (1997). "Getting Round the Lock-in in Electricity Generating Systems: the Example of the Gas Turbine." Research Policy **26**(1): 49-66.

Jacobs, M. (1999). "Sustainable development as a contested concept." In A. Dobson (ed) Fairness and Futurity. Routledge, London.

Jacobsson, S. and A. Johnson (2001). "The diffusion of renewable energy technology: an analytical framework and key issues for research." Energy Policy **28**: 625-40.

Kaldor, M. (1983). The Baroque Arsenal. Abacus, London.

Kemp, R., A. Rip and J Schot (2001). "Constructing transition paths through the management of niches". In R. Garud and P. Karnoe (eds.) Path Dependence and Creation, 269-99. Lawrence Erlbaum Associates Publishers, Mahwah, New Jersey.

Kemp, R. and J. Rotmans (2001). "The management of the co-evolution of technical, environmental and social systems." International Conference Towards Environmental Innovation Systems, Garmisch-Partenkirchen, September.

Kemp, R., J Schot and R. Hoogma (1998). "Regime shifts to sustainability through processes of niche formation: the approach of Strategic Niche Management." Technology Analysis and Strategic Management **10** (2): 175-195.

Leiss, W. (1990). Under Technology's Thumb. McGill-Queen's University Press, Montreal.

Lukes, S. (1974). Power: a radical view. Macmillan, London.

MacKenzie, D. (2001). Knowing Machines: essays on technical change. MIT Press, Cambridge, MA.

MacKenzie, D. (1990). Inventing Accuracy: a historical sociology of nuclear missile guidance. MIT Press, Cambridge, MA.

Mokyr, J. (1991). The Lever to Riches: technological creativity and economic progress. Oxford University Press, Oxford.

Munton, R. (2003). "Deliberative democracy and environmental decision-making." In F. Berkhout, M. Leach and I. Scoones (eds.) Negotiating Environmental Change, 109-136. Edward Elgar, Cheltenham.

Nelson, R. and S. Winter (1982). An Evolutionary Theory of Economic Change. Harvard University Press, Cambridge, MA.

Nelson, R. and S. Winter, (1977). "In search of useful theory of innovation." Research Policy **6**, 36-76.

Patterson, W. C. (1985). Going Critical: an unofficial history of British nuclear power. Paladin, London.

Pearce, D. (1989). Blueprint for a Green Economy. Earthscan, London.

Rip, A. (1995). "Introduction of new technology: making use of recent insights from sociology and economics of technology." Technology Analysis & Strategic Management 7(4): 417-431.

Rip, A. and R. Kemp (1998). "Technological change." In S. Rayner and E. Malone (eds.) Human Choices and Climate Change, Vol. 2, 327-399. Battelle, Columbus, Ohio.

Rip, A., T. Misa and J. Schot (1996). Managing Technology in Society. Pinter, London.

Rosenberg, N. J. (1994). Explaining the Black Box. Cambridge University Press, Cambridge.

Rotmans, J., R. Kemp and M. van Asselt (2001). "More evolution than revolution: Transition management in public policy." Foresight **3**(1): 15-31.

Sahal, D. (1981). Patterns of Technological Innovation. Addison-Wesley, Reading, MA.

Schot, J. (2001). "Towards new forms of participatory technology development." Technology Analysis and Strategic Management **13**(1) 39-52.

Schot, J. (1998). "The usefulness of evolutionary models for explaining innovation. The case of the Netherlands in the 19th Century." History and Technology **14**: 173-

200.

Schot, J. and A. Rip (1997). "The past and future of constructive technology assessment." Technological Forecasting and Social Change **54** 251-268.

Smith, A. (2003) "Transforming technological regimes for sustainable development: a role for appropriate technology niches?" Science & Public Policy **30**, 2, April.

Stirling, A. (2003). "Risk, Uncertainty and Precaution: some instrumental implications from the social sciences." In F. Berkhout, M. Leach and I. Scoones (eds.) Negotiating Environmental Change, 33-76. Edward Elgar, Cheltenham.

van de Poel, I. (2002). "The transformation of technological regimes." Research Policy **32** (1):49-68.

Van de Ven, A., H. Angle and M. Poole (1989). Research on the management of innovation: the Minnesota studies. Harper & Row, New York.

Wajcman, J. (1996). Feminism Confronts Technology. Polity Press, Cambridge.

Walker, W. (2000). "Entrapment in large technology systems: institutional commitments and power relations." Research Policy **29**, (7-8): 833-846.

Weber, M., R. Hoogma, B. Lane, and J. Schot (1999). Experimenting with Sustainable Transport Innovations: a workbook for strategic niche management. University of Twente Press, Twente.

Willoughby, K. (1990). Technology Choice: a critique of the appropriate technology movement. Intermediate Technology Development Group, London.

Winner, L (1981). Autonomous Technology: technics out of control as a theme in political thought. MIT, Cambridge, MA.

Wynne, B. (1992). "Uncertainty and Environmental Learning: reconceiving science and policy in the preventive paradigm". Global Environmental Change **2** (2): 111-127.