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Constructing Transition Paths Through the Management of Niches

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Caminante no hay camino, se hace camino al andar¹
(the traveler has no path, he creates one as he goes)

The phenomenon of path dependency in economic development and technological change is widely recognized. It introduces a historical element and the notion of irreversibility into economic analysis (Arthur, 1988; Hahn, 1989; Organization for Economic Co-operation and Development, 1992) and bridges the gap with sociological analysis (North, 1990).

In this chapter we are less interested in causes of path dependency than in the possibility of intentionally constructing a desirable path. There are different ways to do this. One can try to construct a path by brute force, that is, by planning a new system and working to overcome the barriers to its realization by eliminating them. This is often done in the case of physical infrastructures and complex technical systems like the grid-based electrical

¹From a Spanish song by Antonio Machado.

system. One can also try to bend the development process by judiciously applying economic (or social, for that matter) incentives and disincentives, so as to make some possible paths more, and others less interesting and feasible. Thirdly, one can float with the coevolution processes and modulate them. Depending on circumstances and on the position of the actor who takes the lead (government, public-private consortium, firms, nongovernment organizations, and societal groups), one or the other approach will appear more suitable and/or more advantageous.

Elsewhere, we have argued that the third approach is important in modern societies, and that it is underdeveloped as yet (Schot & Rip, 1997). We have also articulated a method for constructing paths, called *strategic niche management* (SNM—the creation, development, and breakdown of protected spaces for promising technologies. Originally, the method was positioned as making the introduction of new technology more successful (Rip, 1992). Our exposition of the method in this chapter shows the same orientation, for example when specifying enhancing the rate of application of the new technology as the aim of SNM. But the method is now part of a broader framework: the build-up of new technological regimes and the possibility of intentionally working toward desired regime change.

The structure of the chapter is as follows. The next section provides a discussion of patterns in coevolution processes, as a way to broaden the notion of path dependency (Rip & Kemp, 1998). We provide an analysis of such patterns and the role of niches and regimes in coevolution patterns. This helps prepare the ground for a discussion of strategies for achieving technological regime shifts. This discussion is followed by a description of the Californian and Danish wind power policies as examples of two different types of policy approaches. The case of wind energy development is interesting because it shows that an existing electric power regime can become less homogeneous and more open for change. The case is also interesting in that it allows a comparison between *de facto* SNM (in Denmark) and an incentive-based approach (in California). The cases do not permit us, however, to evaluate these approaches in terms of achievement of regime shifts because a regime shift has (yet) not occurred.

We then present and discuss the method of SNM as a way to create a new path through the creation and management of protected spaces for promising technologies and as a tool of transition. Of course, actual transitions are complex and contingent, and it will not be clear, at the outset, whether the path under construction will actually become a transition path. In other words, SNM may well be a necessary element to bring about a transition, but it will not be sufficient. In particular, the stabilization of a new regime as a mosaic of rules (including dominant designs and standardization) has dynamics and patterns of its own. SNM can help sway the balance there, but

needs to be developed further to function as a management tool. When we reflect on the potential and the difficulties of SNM, in the final section, we come back to this issue.

TECHNOLOGICAL REGIMES AND TRANSITION PATHS

Technological change is not an autonomous force, nor is it a haphazard process; it is structured and focused, geared toward solving particular problems that have grown in the process of development, and endogenous to the structure of economic incentives, firms' capabilities, (legal) standards, and economic interests. New technologies are not created outside society, but part and parcel of social-technical transformation processes.

In this transformation process, the frontiers of knowledge shift, new problems emerge, people's preferences change, old institutions dissolve, while others are created. A recurrent theme in the social study of technology is the evolutionary nature of technology in which technical change is seen as bounded and open-ended—bounded in the short term and open-ended in the long run. Rosenberg (1994) speaks of a "soft determinism" (p. 17) that is exercised by technological trajectories. *Technological change* is a path dependent cumulative process in which the existing body of knowledge, techniques and tools determine which further steps can be taken at any time. There is an "overhang of technological inheritance" that shapes ongoing technological research.

There is also second aspect of path dependency, already discussed in an older work of Rosenberg (1976), which is that technological research is essentially a problem-solving activity and that engineering attention is drawn to devote attention to problems that present themselves. In particular, observed imperfections in existing products and processes are instrumental in focusing the attention of engineers on particular problems by throwing up signals about what technological efforts can be usefully exercised (Rosenberg, 1976). This point is developed further in the work of Nelson and Winter (1982), and Dosi (1982, 1988) who writes that technological change is cumulative, selective, and finalized into specific directions somewhat irrespective of the cost and demand structure.

Sociologists focusing on actor strategies and networks take a partially different, but overlapping view. According to one influential representative, Donald MacKenzie, technological trajectories are sustained not by an internal logic but by the interests that develop in their continuance and the belief that the trajectory will continue (MacKenzie, 1992). The very presence of trajectories is a continual and contingent achievement of actors working to stabilize technical change (see Rip, Misa, & Schot, 1995).

Implicit in these approaches is that technological change is not an autonomous, deterministic process but constrained and structured: (a) by engineering consensus about the relevant problems and how these may be solved, (b) by the available methods and techniques, (c) by the organizational and institutional context, and (d) by patterns of infrastructures and demand. The structured nature of technological change means that there is a "grammar" or rule set that shapes ongoing research and investment (Rip & Kemp, 1998). Examples of these rules are: (a) the search heuristics of engineers (about the relevant problems to be solved and how to solve them); (b) the investment selection criteria employed by private firms operating in the market place (with its rules for survival); and (c) organizational procedures, technical standards, social norms, regulatory standards, and rules of ownership and patent protection. These rules are not something that exist outside technology or the organizational and social context in which technology is developed and used but are embedded in engineering practices, process technologies, product characteristics, skills, institutions, and infrastructures of a technology. They are an integral part and structuring force of sociotechnical coevolution processes.

Elsewhere we have used the term *technological regime* to characterize this rule set (Kemp et al., 1994; Rip & Kemp, 1998). Combining both economic and sociological approaches, a *technological regime* is defined as the grammar or rule set comprised in the complex of scientific knowledges, engineering practices, production process technologies, product characteristics, skills and procedures, and institutions and infrastructures that make up the totality of a technology (for example, an internal combustion engine or gas turbine) or a mode of organization (for example, the Fordist regime of mass production). Although others (like Hughes, 1983) used the term *technological system*, we prefer to use *regime* because regime refers to rules: in particular, the rules and grammar that are implied in sociotechnical configurations. The notion of regime also allows for a better appreciation of the decentralized multiactor dynamics at play in technical change.

Technological regimes are a broader, "socially embedded" version of a technological paradigm. A technological regime combines the rules that are embedded in engineering practices and heuristics with the rules of the selection environment. Accordingly, our definition differs from that of Malerba and Orsenigo (1993) and Dosi, Malerba, and Orsenigo (1993) where a technological regime comprises a particular combination of technological opportunities, appropriability conditions, degree of cumulativeness of technological knowledge, and characteristics of the relevant knowledge base (Dosi et al., 1993). The idea of regime is used by the authors to explain differences in innovation patterns and sectional structures, to explain what Nelson and Winter (1977) called the "differential productivity growth puz-

zle" (p. 41). Their definition revolves around knowledge: cumulateness, tacitness, and publicness of knowledge and how new products embodying knowledge may be protected against imitation. Our definition is less about knowledge and more about rules defining innovative activities. There is a second important difference. In Malerba and Orsenigo's (1993) definition, the demand aspects and broader social aspects (norms, lifestyles) are virtually absent, whereas in our definition, they are an important constituent part of a regime. Because of this, our definition is more in line with the way in which the concept of regime is used in studies of international relations, political science, and figuration sociology (e.g., Spier, 1995).

Technological regimes, as we define them, are configurations of science, technics, organizational routines, practices, norms and values, labeled for their core technology or mode of organization. Between the different elements, strong and weak linkages occur, creating a semicoherent structure that serves to guide engineering activities in particular directions and not in others. The prefix "semi" is important, because such structures are not perfectly coherent: there are tensions in the form of product imperfections, side effects, bottlenecks (reverse salients or system limits), and unsatisfied demands (of consumers or general public). There may also be different competing designs. Designs are not given as such but evolving. The way in which they evolve, however, is not ad random but structured. In particular, designs are structured by the accumulated knowledge, engineering practices, value of past investments, interests of firms, established product requirements and meanings, intra and interorganizational relationships, government policies, that make up a technological regime.² This is the key tenet of (quasi) evolutionary approaches of technological change.

The concept of a technological regime is important not only to understand the prestructured nature of technological change but also to come to terms with the problem of technological transition. Viewing it as a process of transformation of an old regime (or a set of regimes) into a new one, the question central to transition processes can now be addressed as one of how regimes change. For example are they transformed through external pressure or by internal inconsistencies and system limits? There is little theory about the issue. All we have are historical accounts of technological transitions that emphasize different aspects of what causes old systems to fall into decline and new systems to grow. One explanation emphasizes the role of system builders. In this view, new systems are created by system builders—people of imagination and persistence who perceived early on the op-

²It should be noted that it is not just a matter of mind sets of engineers who are committed to a particular technology. Also policy actors, companies, and consumers are directly or indirectly, willingly or unwillingly, committed to a particular technological regime (e.g., the fossil fuel-based electric system).

portunities offered by a new technology, who conceived the new technology as the constitutive part of a new system, and who managed the transition process toward a new system. History of technology is often written around these entrepreneurs, picturing them as people of vision and determination. The names of Edison, Insull, and Mitchell are then associated with the development of the electric power system (Hughes, 1979, 1983). There was Edison, the inventor-entrepreneur who built the first electric power system; Insull, the manager-entrepreneur, who managed the expansion of the electric system, uniting local systems to larger ones; and Mitchell, the financier-entrepreneur who introduced financial and organizational means (such as the holding company) by which the growth of the utilities could continue on a regional level (Hughes, 1979). All of them had a vision of what the new system should look like and were determined solvers of the many problems frustrating the growth of the system.

Although we do believe system builders play an important role in regime changes, in many cases the future use of the new technology is not clear at the outset nor anticipated and thus not engineered in any important way, which downplays the system building element. One example of an unanticipated use of a radical technology is the radio (Rosenberg, 1995). At the time of its invention, the radio was seen not as a means of mass communication but as an alternative to the telegraph, to communicate between two points where communication by wire was impossible. It would be used for private communication, that is, for narrow casting, not broad casting. The users that were envisaged by Marconi were steamship companies, newspaper companies, and navies (Rosenberg, 1995). A similar story can be told for the steam engine. Originally, the steam engine was viewed, and used, as a pumping device. After the 18th century, however, the pump developed into an industrial power source, a propulsion technology (first in ships, later in trains and road vehicles), and finally, an electric power technology. Computers are a recent example of a technology whose final use and dominance was not anticipated. At the time of its invention, the computer was thought to be of potential use only for rapid calculation in scientific research or data processing contexts. The prevailing view in the late 1940s was that world demand could be satisfied by just a few computers (Rosenberg, 1995).

In situations in which the new system is the long-term outcome of the planned and unplanned actions of many actors (which in our view is the common case), *niches*, limited domains in which the technology can be applied, play an important role in the transition process. Military demand often provided a niche for a new technology, but the market system sometimes provide niches as well. The steam engine was developed by Newcomen to pump up water from mines; clocks were first introduced in monasteries where life was arranged according to strict timetables; the origin of the as-

sembly line began with the American army in Springfield, Massachusetts, where the manufacture of muskets was standardized to the extent that all components were interchangeable; and the wheel was first used for ritual and ceremonial purposes (Schot, 1998). These niches were important for the take-off of a new technological regime in several ways: (a) they helped to demonstrate the viability of the new technology, (b) they provided financial means for the further expansion, (c) they fostered support from customers, investors, suppliers and other actors, and (d) set into motion interactive learning processes, the development of complementary inventions, and institutional adaptations—in management, organization, and the overall institutional framework in which firms operate—that are all important to the wider diffusion of the new technology.

Niche developments happen in two (partly overlapping) forms: in protected spaces and in the market place. Niche development often starts in protected spaces, where regular market conditions do not prevail because of special protection in the form of research and development (R&D) programs (of companies and governments), subsidies or loosening of institutional constraints (as in skunk works*). Such protected spaces can be called technological niches to distinguish them from market niches. They often take the form of experiments. Examples are experiments with electric vehicles in various European countries and cities (Rochelle, Rugen, Gothenburg, etc.***) which would not be possible without the sponsorship and support of different actors. Technological niches often precede market niches. Both processes of niche development can occur simultaneously and reinforce each other. For example, the introduction of electric vehicles in certain market niches might stimulate the emergence of new technological niches for a new type of customer. *Niche development* is a process of niche expansion and proliferation resulting in new ecology of niches. Key processes in niche development are: the refinement and coupling of expectations, articulation of problems (like production imperfection, side effects), needs

*Skunk works consist of special teams of researchers, production engineers and marketers doing dedicated work on a novel product free from normal business constraints.

**La Rochelle refers to the user experiment with electric vehicles in the French town La Rochelle. The experiment started in Dec 1993 and lasted 2 years. In this period 50 prototype Evs (25 Peugeot 106 and 25 Citroën AX) were used by private people who volunteered to use such vehicles. The experiment sprang from the existing co-operation between the 3 main actors: PSA, EDF and the Municipality of La Rochelle. The aim of the project was to investigate this market. User experiences were very promising but sales of electric vehicles were disappointing. The La Rochelle experiment showed that in the current regime of car use, electric vehicles for private use can not survive without special protection. Rügen consisted of a large-scale experiment with 60 prototypes of battery-powered electric vehicles on the Island of Rügen in Germany. The vehicles were converted internal combustion engine vehicles produced by German automobile manufacturers. The vehicles were used by 100 user organisations over a period of 4 years. At the time of the start of the experiment, in 1992, it was the biggest experiment with electric vehicles. The experiment confirmed the negative view about Battery Evs in the German car industry and their choice to focus on other options such as fuel cells.

and possibilities, and network formation (Schot, Slob, & Hoogma, 1996; see also Elzen, Hoogma, & Schot, 1996; Kemp, Schot, & Hoogma, 1998).

Niches and entrepreneurial activity are important for the take-off of a new regime, but there is a third factor: the knowledge, skills, techniques that are available at any given time plus the support from parties who stand to gain from the new development. For their development, new technologies often depend on the old technologies, in particular the accumulated knowledge, capabilities, and skills acquired in existing technological regimes. Without these skills, technologies and the support from organizations having an interest in the development of a new regime, the system builders would have gotten nowhere and niches would not have emerged. Historically, the automobile benefited from experience accumulated in bicycle and carriage production. Electrical engineering firms played an important role in modern wind turbine development, as did semiconductor firms in the development of solar cells. The development of new technology thus depends on the characteristics of the existing technological regimes and the overall sociotechnical landscape.

In our view, all three factors—system builders (entrepreneurs), niches and the institutional support and capabilities of actors in existing regimes—are necessary for a regime shift. Without a market application, the technology will remain an idea or prototype, and in order to find a market application, there must be entrepreneurs to manage the “junction between the entrepreneurial firm and multiple market places” (Star & MacMillan, 1991, p. 167). The success of entrepreneurial activities, however, will depend not just on the managerial skills of the entrepreneur but also on the knowledge, skills, and assets that are available at the time, and the prevailing cost and demand conditions.

The story of novelty creation and regime change is depicted in Fig. 10.1. A distinction is made between three levels at which processes of sociotechnical change occur: the level of individual firms and households, the level of technological regimes, and the level of sociotechnical landscapes. The technological regimes and sociotechnical landscape of roads, villages, farms, and factories provide the backdrop to novelty creation; they shape the process of novelty creation by providing the means to produce the new technology and defining economic possibilities for their use. In turn, the regimes and landscape are transformed by the novelties and practices that go with them. This is the key process: the overall sociotechnical system and landscape with its different technological regimes create opportunities for sociotechnical change. And the exploitation of these opportunities by firms and other actors opens up yet further possibilities.

Our claim is that the success of niche formation is governed by processes within the niche, and by developments at the level of the existing regime and the sociotechnical landscape. So it is the alignment of develop-

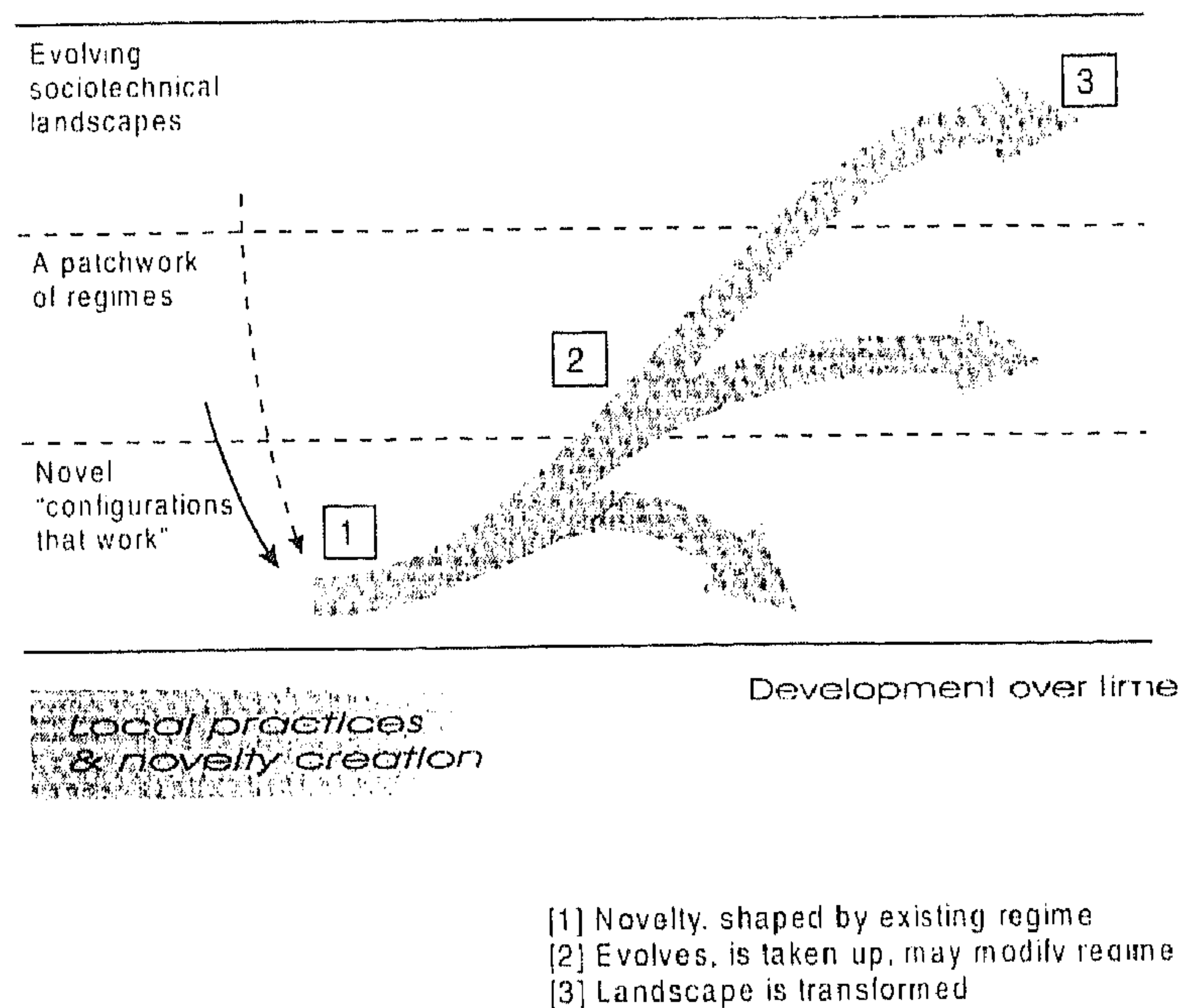


FIG. 10.1. The dynamics of sociotechnical change at the different levels of the technology-society relationship. Figure 10.1 shows that local practices, including those that involve novelty creations, occur in a context of regimes and the sociotechnical landscape, with exert influence on the shape and success of novel products.

ments—successful processes within the niche reinforced by changes at regime level and at the level of the sociotechnical landscape—which determine if a regime shift will occur.

This view differs from Arthur's (1988) model of path dependency. Arthur assumes two competing emerging technologies, whereas we consider the existence of a dominant, fully developed technology embedded in a technological regime that is challenged by a new emerging technology. The latter case is probably more common (see Islas, 1997).

In this scheme, technological regimes are the key element. They are both the *backdrop* and *setting*, that is, both the context and place in which novel products are conceived, developed, and introduced. Novelty originates within existing regimes, starting at the microlevel of local practices, and their success is linked in some way to structural problems or even crises of an existing system (Smith, cited in Kemp, Miles, Smith, Boden, Bruland, van der Loo, Street, Wicken, with Andersen, Freeman, & Soete, 1994). When

the new technologies become more robust, benefitting from dynamic scale and learning economies and from institutional adaptations, finding new applications, and getting embedded into the social environment, irreversibilities increase and a reversal may occur. The technology now becomes a force of its own, and the context for newly emerging technologies, setting the terms of competition for other technologies. Having broken up sociotechnical relationships, it now fixes others (Rip & Kemp, 1998).

A good example of the aforementioned model is the evolution of the computer. From the turn of the century onward, a computing regime had evolved where calculations (in astronomy, in ballistics) were done by instructions to rooms full of women with calculating machines. These tasks could be substituted by the first electronic calculating machines of the 1940s. Further steps in the development of these protocomputers were geared to existing regimes, and to evolving possibilities of these new configurations (machine codes, machine languages, and then programming languages, which created a certain independence from the particular contexts of use). One can trace the developments in detail (Van den Ende, 1994). The important point is that it was only by the 1960s that the possibilities of the computer itself became the driving force of developments, also in other sectors.³ A reversal occurred, and from the 1960s onward, one can speak of a computer regime. In other words, a transformation of regimes occurred, but not because an external input, the new computer, forced such a change; the computer could emerge and develop only within the existing regime, and an eventual transformation depended on this evolution.

HOW TO CHANGE TECHNOLOGICAL REGIMES?

Having discussed the problem of transition as a problem of regime change, we now ask the question whether it is possible to manage a transition process into a new regime (e.g., a more sustainable energy or transport system). It is clear that a shift toward an alternative technological regime presents a huge problem for public policy makers (or anyone else, for that matter). The task is no longer to control or promote a single technology but to change an integrated system of technologies and social practices in a nondisruptive way; that is, without causing social problems and welfare losses in the transition process. This is the problem that public policy makers face if they set out to promote a shift toward a different technological regime, like a transition to an alternative transport system. But how to do this? In our view there are basically three options.

³This is not to say that there had not been expectations about the potential of the computer, and attempts to realize them, often based on support from the military (Edwards, 1995). But until the 1960s, this took place in niches, and no new regime emerged.

The first strategy is to change the structure of incentives and let market forces play. This is the kind of approach favored by economists. Instead of engaging in the search for technologies to solve specific social problems, policymakers should change the structure of economic incentives: tax negative externalities and reward positive externalities. The advantage of this strategy is that decisions are decentralized, made by individual actors. Technology choices are left to the market rather than to a bureaucratic agency. Applied to environmental problems, this strategy promises that environmental benefits can be achieved at the lowest cost.

The arguments in favor are well known. There are good reasons to use incentives and even make them a central part of government policies, but there are also problems with incentive-based approaches, and these need to be pointed out. One problem is that the policy measures have to be really drastic in order to have an impact, considering the dominance of existing technologies. Even a tenfold increase in world market oil prices in the 1973–1983 period (from \$3 to \$30 per barrel) did not bring about a shift toward renewable energy sources; fossil fuels continued to be the main energy sources. It promoted energy efficiency improvements in energy generating and use technologies, but it did not lead to a replacement of fossil fuels by alternative renewable energy sources. The use of economic incentives can also lead to (temporary) windfall profits for manufacturers and dead weight losses for consumers. There is a third problem with the use of government incentives, which has received far less attention: The taxes and subsidies need to be accompanied by corrective measures that limit the negative effects of the wide-scale use of alternative technologies that are favored by the tax regime. No technology is perfect. All technologies have their side-effects and drawbacks. Thus, unless the use of economic incentives is accompanied by other policies aimed at limiting the harmful side effects of alternative technologies, incentive-based policies are bound to cause a transfer of problems.

The second strategy is to plan for the creation and building of a new sociotechnical system based on an alternative set of technologies, in the same fashion as decision makers have planned for large infrastructure works, like coastal defence systems or railway systems. The problem with this approach is that in modern, pluralistic, and advanced societies, a new technological system cannot be completely planned; the integrated nature of technology and complex social aspects defy a rational planning approach. In general, goals and human needs are too general and manifold to provide a precise guide to planners and technology developers. Even for firms it is often difficult to know what their own clients want. User requirements are articulated in relation to the technologies that are available; we learn what we want through experience (Truffer, Cebon, Dürrenberger, Jaeger, Rudel, & Rothen, 1999). Moreover, our wants and needs change over time.

The third and last strategy is to build on the ongoing dynamics of sociotechnical change and to exert pressures so as to modulate the dynamics of sociotechnical change into desirable directions. For this strategy, the task for policymakers is to make sure that the coevolution of supply and demand produces desirable outcomes, both in the short run and in the longer term. Rather than laying down requirements policymakers need to engage in process management to keep the process of sociotechnical change going into the right direction.⁴ In contrast to the traditional policy approach, which starts from a stated goal after which a set of instruments is selected to achieve this goal, process management does not start from a quantified goal but from a set of partially conflicting goals. It aims to (a) change the rules of the game; (b) to shape the interactions and strategic games between different actors representing different interests and capabilities (for example, by empowering certain voices, making sure that the process is not dominated by certain actors); and (c) to keep the process of change going in desirable directions by counteracting undesirable effects and amplifying desirable ones. Although there are no principle problems, and the strategy may be the only feasible one in contemporary society, the practicalities are less clear. How is the modulation to be done?

Our discussion of technological transitions as a process of niche proliferation suggests one possible strategy to manage the transition process: Start by creating protected spaces, or niches, for promising new technologies. These spaces, in the form of technological niches, function as local breeding spaces for new technologies, in which they get a chance to develop and grow. Once the technology is sufficiently developed, and broader use is achieved through learning processes and adaptations in the selection environment, initial protection may be withdrawn in a controlled way. This strategy is called *strategic niche management*. It was first described in Rip (1992) and elaborated in Schot et al. (1996) and Kemp (1997). We describe strategic niche management as a way to induce and manage technological regime shifts. But before we do, it is useful to look first at some actual energy technology policies aimed at creating new paths—the Californian and Danish wind power policies—to get a better idea of the difficulties and problems in creating alternative paths of development. This case does not show a complete regime shift but it will help to clarify why strategic niche management is a potentially useful approach.

THE CALIFORNIAN AND DANISH WIND POWER POLICIES

This section describes the Californian and Danish policies toward wind power. Both policies are instructive in demonstrating some advantages of a bottom-up

⁴The use of process management as a means of sociopolitical governance has been advocated by various policy scientists (see for instance Glasbergen, 1994; Kooiman, 1993).

approach over a top-down approach. The policy descriptions draw on the work of van Est (1999), Righter (1994), Cox, Blumstein, & Gilbert (1991) and Grubb (1992) for the United States, and Lauritsen, Svendsen, & Sørensen (1996) and Jørgensen and Karnøe (1995) for Denmark.

The Californian Wind Power Policy

In the 1980s, California became the world center of wind energy development (Cox et al., 1991). Between 1981 and 1990, some 15,000 wind generators were erected (Righter, 1994). Installation rates in California rose from 10MW in 1981 to 60MW in 1982 and trebled in each of 1983 and 1984 to a level of 400 megawatts (MW) a year. The cumulative investment in Californian wind energy by 1986 totaled about \$2 billion (Grubb, 1992). Of all the electricity produced from wind in the world during 1985, 87% was produced in California (Cox et al., 1991).

This development was largely the result of federal and California tax subsidies and buy-back regulation. Between 1930 and 1970, there was virtually no interest in wind power (Righter, 1994). There were no wind turbine manufacturers and little expertise in wind mills; wind mills had lost out against the expanding central electricity system in the 1930s. Most of the old windmills were manufactured elsewhere. Interestingly, for the purpose of argument, California can claim a unique windmill, in the form of a 10-ton, 70-foot, bell-shaped tube, developed by an inventor-entrepreneur, Dew Oliver, in the 1920s. The turbine looked like anything but a windmill. It consisted of a giant moveable metal tube that sat on a circular track atop a concrete foundation. Within the tube, there was a series of propellers mounted on a horizontal shaft; the propellers turned two generators, capable of producing 200 horsepower. Oliver raised \$12.5 million from investors for his invention but the tunnel system generator never went into commercial operation. Oliver's business floundered and Oliver ended up in jail for breaking security laws. In a sense, this event already anticipated some later events during the "Californian wind rush" (based on Righter, 1994).

The phrase "wind rush," coined by Grubb (1992), indeed seems appropriate for much of what happened in the 1980s, when private investors, attracted by favorable tax incentives, entered the newly created market for wind power. In California, a 25% energy tax credit was offered for investment in renewable energy sources on top of the 15% federal energy tax credit for investment in renewables and a 10% federal general investment tax credit.⁵ In addition, in 1978, Congress passed the Public Utility Regula-

⁵The California energy tax credit was eliminated on December 31, 1986, after been reduced to 15% on January 1, 1986. The federal tax credit for wind turbines, introduced in 1978 as part of the Energy Tax Act, expired on December 31, 1985.

tory Policies Act (PURPA) which required utilities to purchase electricity from independent power producers at prices corresponding to avoided costs. The policies were supplemented by a federal research and development programs for wind energy (mostly for large machines), soft loans, and accelerated depreciation schemes.

There do not exist many accounts of the California wind power policy process. The main source of information on which we draw is that of van Est (1999). According to van Est, politics played an important role in the whole development of wind power. In the United States, there was a strong soft energy movement, which propagated the use of renewables, especially solar energy. There was also a small but active solar industry. It is doubtful that the soft energy movement would have gotten very far without the 1973–1974 Arab oil embargo. When the oil embargo hit the United States in December 1973, the country was in a crisis. President Nixon unveiled Project Independence, aimed at making the United States independent of any source of energy outside its border by 1985. In 1975, the Congress launched the Energy Research and Development Administration with a division of Solar Energy. Interestingly, wind power received little attention; most of the attention and support went to solar power that, unlike wind power, was seen as a back-stop technology capable of totally replacing fossil and nuclear power plants.

Wind energy, which at the time was viewed as a limited energy source, benefited from the attention given to self-sufficiency and solar power. In California, in a 1978 revision of the 1977 solar tax-credit law, wind power was included as another renewable qualifying for support. Before 1978, there was hardly a wind power policy, and in a way the whole development of wind power in California was accidental. Wind energy was the primary beneficiary of three policies that were not really aimed at wind power, namely the (a) 1978 Public Utilities Regulatory Policies Act, which broke down the monopoly position of power utilities and established a favorable regime for independent electricity producers; (b) the National Energy Act of 1978, which provided a 15% federal energy tax credit for investment in renewable energy sources; and (c) the 25% California energy tax credit for investment in renewables, none of which was aimed particularly at wind power. As to the crucial requirement in PURPA that obliged utilities to purchase electricity from independent power producers at prices corresponding to avoided costs, this was only a minor part of a complex piece of legislation that did not receive much attention in the political process.⁶ The effects it would have on the business of power production

⁶Some say that the utilities accepted the PURPA requirement as a goodwill gesture, without realizing how it would change the energy business. According to others, Congress mistook Section 210 of PURPA as the federal equivalent of the Private Energy Producer Act in California, designed to encourage private producers to competitively develop independent sources of natural gas and electric energy for their own use. In any case, PURPA went far beyond the California law by opening up opportunities for independent power producers that were unanticipated (van Est, 1999).

in the United States were not anticipated. The 15% tax credit under the Energy Tax Act also did not receive much attention at the time, it was passed by Congress, according to Cox et al. (1991), "almost as an afterthought".⁷

The California energy policies were more targeted toward wind power. The 1978 Mello Act established the goal that, by 1987, 1% of California energy would be produced by wind generators, rising to 10% by 2000, but these goals it seems played a minor role in public and private wind energy development decisions. A California proposal to implement a \$80,000,000 state wind energy program was rejected by the Committee of Resources, Land Use and Energy and by the Senate. The Senate did approve a \$800,000 plan to identify high-wind sites that, according to van Est, proved to be very influential in the startup of wind farms in California. Furthermore, the Office of Appropriate Technology (OAT), established in 1976 by Governor Brown to promote energy self-sufficiency, had a wind energy program for small wind energy conversion systems. Even though the OAT program was nothing more than a small dissemination program offering guidance to people who wanted to construct a turbine, it had an important impact in preparing the ground for wind farms (van Est, 1999). The increasing attention given to wind power led to the (in retrospect) misconceived idea (even among the utilities) that the technology was sufficiently developed and economical to use, and lured by the expectation of high profits, many companies rushed in. The profits to be captured from setting up a wind farm were indeed high. According to Cox et al. (1991) "most investors could recover about two-thirds of their investment through the reduction of their taxes in less than three years, even with no sales of electricity. If the turbine did perform as projected, the investor could expect to earn a high return (10-20%) from the investment" (p. 349).

The tax incentives and buy back rates on the basis of full avoided costs created a bonanza of opportunity for wind energy (Righter, 1994). Installation rates in California grew from 7MW before 1982 to 1,121MW in 1985. With the market base and finance of California, several companies invested heavily in wind energy technology and gained rapid experience. Major improvements in machine performance were achieved that led to a higher availability and doubled capacity rates in the 1980s. Capital costs fell from \$3,100/kilowatts (kW) in 1981 to an estimated \$1,250/kW average in 1986 (historic prices) (Grubb, 1992). However, the quick expansion was achieved at a considerable cost. As Grubb (1992) accounts: "Many of the early machines installed were of poor quality, and some broke in the first season of operation ... Machines were often sited carelessly and very densely,

⁷According to Ron White, who attended the hearings of the Joint Committee on Taxation, this was not true. The Energy Tax provision received a great deal of attention at the time. According to him, a source of the problem was the U.S. federal system, with its different levels of government, with inflexible federal policies working out differently in states.

and some were sold on fraudulent promises" (p. 170). The bad performance of the machines was not just an engineering failure; it was also caused by the perversity of the tax system in which the tax benefits were based on turbine capital costs rather than performance, and which allowed a developer to "sell inferior machines at a hefty profit" (Cox et al., 1991, p. 350). In 1985, the California wind industry produced only 45% of the energy they projected it would produce (Cox et al., 1991).

Looking back, it is clear that the Californian wind power policy was not a success. There had been too-rapid investments in an immature technology, the subsidies were too high, creating windfall gains for the wealthy, and too little had been done to prevent the construction of simply bad turbines. In an interview, Thomas Thompson of the Californian Public Utilities Commission (CPUC) admitted that the CPUC had made "two classic economic blunders" by not adjusting prices and not restricting the volume that could sign up (van Est, 1999, p. 60). The perversity of the tax credit program—where investors obtained tax benefits whether the equipment performed adequately or not—was acknowledged by the California Energy Council but they did not want to raise the issue with a new governor hostile to wind power and rising opposition to wind turbines. They felt that reopening the legislative issue was like opening Pandora's Box (van Est, 1999).

It is clear that many of these drawbacks could have been prevented by more carefully designed policies and timely revisions of the policies. The experiences did not disqualify the use of economic incentives as the basis of (energy) policy per se. As noted in Kemp (1997), there are many good reasons for using incentive-based approaches. However, it brings out some of the disadvantages of economic incentives as the sole policy instrument. By establishing a regime of tax credits and guaranteed rates, the government had little control over the number of wind farms that were established, nor did it have much influence over the choice of wind turbines in the absence of a standardized performance rating system (Cox et al., 1991). The sight of ugly, motionless machines damaged the reputation of wind energy, and was an important factor in the decision to eliminate the state tax credits on Dec 31, 1986, 1 year after the elimination of the federal tax credits, which sent many wind turbine companies into bankruptcy (in California and in Denmark) and suspended a reasonably benign energy source.

The Danish Wind Power Policy

The Danish policy toward wind power differs in several respects from that in California: It was less general, more specifically aimed at wind power, the policy was adjusted to (changing) circumstances, and, most important, combined elements of promotion and control. The Danish policy combined

several elements of strategic niche management described in the next section, although it never was conceived in these terms by those involved in the creation of wind power—policy actors, politicians, wind turbine manufacturers, and grass-root entrepreneurs.

As in California, the Danish policy emerged in the second half of the 1970s, after the 1973–1974 oil crisis when oil prices were soaring and energy diversification and self-sufficiency were put high on the political agenda. An important difference with the California policy was that the Danish policymakers did not attempt to jump start the development of wind power. In Denmark, a much wider range of policy instruments were used, ranging from R&D support programs, tests, siting regulations, certification schemes, investment subsidies, to streamlining of planning procedures and longer term energy planning. Perhaps more important, besides political circumstances, the policies evolved with experience and changing economic circumstances. The role of the government was also different; less of a sponsor, and more of a counselor and process manager responding to specific problems and opportunities that emerged during the process of development. The development of wind power in Denmark was not staged or engineered by government authorities in an important way. Rather, the policies emerged out of a political process in which different parties had an input, and they reflected real-time experiences and changing economic and political circumstances in Denmark and the rest of the world.

As to the political actors, Jørgensen and Karnøe (1995) noted the importance of the antinuclear movement, organized in the Organization for information about Atomic Power (OOA). The OOA was important in positioning renewable energy sources as a necessary element in Denmark's future energy policy. It articulated the vision of local self-sufficiency and democracy, a vision in which renewables fitted but atomic power and large-scale fossil-fired power plants did not. Perhaps more important, the OOA aimed to present realistic alternatives to nuclear power. It joined forces with established physics researchers, which led to the "alternative energy plan" for Denmark, published in 1976. In this plan, wind power was selected as one of the future energy sources (among other alternative energy sources). Another important influence was the Organization for Renewable Energy (OVE) established in 1975. The OVE organized wind meetings, which brought together all kinds of people engaged in the construction of wind turbines. It also acted as an important forum for the diffusion of knowledge, experience and new ideas. Between 1974 and 1979, a great variety of wind turbine designs were constructed and tested by do-it-yourself builders and small companies.

Lauritsen et al. (1996) provided a somewhat different account than Jørgensen and Karnøe. They mark the establishment of the Wind Energy Committee by the Danish Academy of Technical Science council in Octo-

ber, 1974, as an important event in the development of wind power in Denmark. The task of the Wind Energy Committee was to investigate the possibility of wind energy in Denmark and a Danish wind turbine industry. The committee produced two reports in which it concluded that wind power was potentially economically viable and advocated a wind power development and demonstration program of 56,000,000 Danish kroner. Most of the money was for large unit wind power plants, as in the United States and the Netherlands.

The attention for wind power from both a political, social, and engineering point of view, stimulated the development of wind power. In the 1970s, all kind of experiments were done with different designs and unit sizes. Small size turbines were pioneered by grass-roots entrepreneurs and do-it-yourself builders in the 1974–1978 period. The first turbines were purchased by idealistic buyers whose early purchases help to build expertise. After 1977, a wind turbine industry emerged, consisting of companies that used industrial manufacturing techniques and standardized industry produced parts, using a design pioneered by Johannes Juul, a Danish engineer, in the 1950s. In 1978, a test station for small unit turbines was established in Risø, as part of the government's wind energy research program. According to Jørgensen and Karnøe (1995), the test station was very important in establishing a new industry. It worked as the common R&D department and played an important role in fostering cooperation among competing, antagonistic companies. Beyond this, the tests and accreditation scheme helped to establish a positive image for Danish wind turbines.

The development of wind power was supported by the decision of the Danish parliament to provide a 30% investment subsidy for wind power plants that were approved by the test station. The investment subsidy was lowered to 20% in 1981, increased to 30% in 1982, and reduced to 25% in 1983, and gradually reduced to 10% in 1988, the last year of investment support. In 1984, a 10-year agreement was signed between the utilities and the wind turbine owners regarding buy-back prices and grid connection costs. The utilities agreed to pay a price of 85% of the electricity sales prices for electricity delivered to the grid, on the condition that all electricity was delivered to the grid, if only a part of the production was delivered, the payment was 70% of the electricity price. The utility furthermore agreed to pay 35% of the grid connection costs. For private owners of wind turbines, there was a refund of the energy taxes and CO₂ taxes on top of the 70% to 85% buy-back rate. In 1985, an agreement was signed between the utilities and the Department of Energy to set up 100 MW wind power plants before 1990, followed by a second 100 MW agreement in 1990 to install an extra 100 MW wind power plants before 1994. The increasing institutionalization of Danish (wind) energy policy was underpinned by the Energy 2000 plan that came out in 1990, stating that by the year 2005,

10% of Danish electricity consumption should be generated by wind power. The government intervened in 1991 when the renegotiation of the 1984 agreement between the wind turbine organizations and utilities failed. Some limitations with respect to the size and ownership of private turbines were repealed in 1992.

The policies slowly emerged with the development of wind power technology; first they concentrated on research, development, and demonstration, the setting of quality and reliability standards; and later, when reliable technologies were available, a market was created through investment subsidy policies that were gradually phased out. The policies were more or less supportive; the government did not act as a sponsor or regulator but assumed the role of a catalyst and mediator by building on initiatives and exerting pressures in the strategic games between different groups, notably the utilities, private wind turbine owners, turbine manufacturers, and land use planning authorities. It was an example of a successful energy technology policy that helped to build a new industry (with exports worth \$1,400,000,000 in 1990) and at the same time achieved environmental benefits in a cost-effective manner. Not all of its policies turned out to be a success; in retrospect, the decision to fund the development of large wind turbines proved to be wrong.⁸ The gradual upscaling of small-scale wind turbines, from less than 55 kW in 1980–1983 to 600 kW in 1995, proved to be more economical.

From the perspective of regime management, the Danish policy is very interesting. It confirms our model of technological transitions about the importance of the coincidence of successful niche policies against the backdrop of changing regimes. It also shows the importance of learning, the creation of new actor networks, and changes in the institutional framework. More importantly, it demonstrates some of the advantages of a flexible, sequential policy aimed at modulating the dynamics of sociotechnical change into socially beneficial directions and using windows of opportunity within the evolving dominant regime. Unlike the California policy that merely created a market for wind power through tax credits and buy-back regulation, the Danish policy toward wind power was much more oriented to learning, fostering collaboration and institutional adaptation, and correcting undesirable outcomes. Before a decision to support wind power was made, the feasibility of wind power was investigated, the outcomes of which were used for a research and development program. A wind turbine test station was set up to weed out dismal products, the choice of turbine design was left to the market (and not perverted by adverse government incentives). Furthermore, the government did not underwrite a large part of business risks, and there were no radical policy changes that created false expectations and

⁸It was not necessarily a waste of money. Some of the knowledge that was generated could be used in building small turbines and could be usefully applied in developing today's big turbines.

business booms and busts as had happened in California. Protection of wind power was never too strong so as to dull incentives for technical improvement and cost reduction, and market stimulation incentives were gradually phased out when the technology became more mature.

The policies contributed to the unforeseen success of the Danish wind turbine industry, although the success owed a great deal to other, arguably more important, factors; in particular, the accumulated expertise in wind turbine technology, the work of grass-root entrepreneurs, the powerful antinuclear movement, public support for wind power, and the California market for wind power. What made the Danish policy so successful however (far more successful than the Californian policy or the Dutch policy that was quite similar to the Danish policy) is that it built on the ongoing dynamics of sociotechnical change and modulated these changes. It did not act as a sponsor nor as a regulator but more like a process manager, using both support and control measures.

Strategic Niche Management

From our discussion of continuity and change in technological regimes, strategic niche management (SNM) emerged as a possible strategy to manage the transition process into a different regime. The relative success of the Danish wind power policy showed the importance of process management, in general and as a *de facto* implementation of SNM. We now approach the issue from the other side, and set out an approach for SNM as we distilled it out of our studies of societal experiments with alternative motor cars and transport systems.

Strategic niche management is thus the planned development of protected spaces for certain applications of a new technology.⁹ The SNM approach differs from the "technology push" approach by bringing in the knowledge and expertise of users and other actors into the technology development process. This generates interactive learning processes and institutional adaptation. The SNM approach differs from technology control policies by being aimed at the development of new technologies; the development aspect is an important aspect of strategic niche management.

The idea behind creating a protected space for a promising technology is that the new technology gets a chance to develop from an idea or prototype, or (in the case of motorcars) a showpiece on exhibition into a technology that is actually used. Such use is important for articulation processes to take place, to learn about the viability of the new technology and to build a supporting network around the product. SNM is more than just experimenting

⁹An example of the creation of a protected space at the company level is the formation of a team of designers by a car company intended to develop a new, environmentally friendly car concept. The design team is given a laboratory of its own and not hindered by a number of design restrictions that apply to the regular development of prototypes (such as cost restrictions and choice of materials).

with a new technology, however; it is aimed at making institutional connections and adaptations, at stimulating learning processes, both of which are necessary for the further development and use of the new technology.

More specifically, the aims of SNM are:

- To articulate the necessary changes in technology and in the institutional framework that are necessary for the economic success (diffusion) of the new technology;
- To learn more about the technical and economical feasibility and environmental gains of different technology options—that is, to learn more about the social desirability of the options;
- To stimulate the further development of these technologies, achieve cost efficiencies in mass production, promote the development of complementary technologies and skills, and stimulate changes in social organization that are important to the wider diffusion of the new technology;
- To build a constituency behind a product—of firms, researchers, and public authorities—whose semicoordinated actions are necessary to bring about a substantial shift in interconnected technologies and practices.

The management of niches can be done by firms, governments, and other social actors, but need not necessarily occur in a systematic and coordinated way. Actors have different interests, technological capabilities, powers, belief systems, and expectations. Moreover, there are usually several technological options that compete with each other.

How are technological niches created and managed? From a managerial rather than a process perspective, SNM consists of five interrelated steps: the choice of the technology, the selection of the experiment, the set-up of the experiment, the upscaling of the experiment by means of policy, and the breakdown of protection.¹⁰ These steps should not be perceived as consecutive steps, but rather as overlapping and interrelated activities. The time dimension is important, however, insofar as the activities to be undertaken at a later stage build on earlier, often irreversible decisions in previous stages. This implies the need to anticipate the requirements of later stages in the initial design phase.

The Choice of Technology

There are usually different types of solutions for a problem, with different costs and benefits. A choice must be made as to which technology should be supported. Technologies particularly eligible for support through SNM are

¹⁰We have been developing the SNM perspective for cases in which technologies are promoted by governments for their relevance to solving environmental problems. This influences our framing of SNM. A workbook for the implementation of SNM is under development (Weber, Hoogma, Lane, & Schot, 1998).

technologies that are outside the existing regime or paradigm but that may greatly alleviate a social problem (like environmental degradation or road congestion) at a cost that is not prohibitively high. For contributing to a regime change, the technology has to meet four additional criteria, apart from the social precondition. It must:

- Have major technological opportunities embedded in it, have sufficient scope for branching and extension and for overcoming initial limitations (*Technological—scientific precondition*).
- Exhibit increasing returns or learning economies (*Economic precondition*).
- Be consistent with actual or feasible forms of organization and control and be compatible with important user needs and values of early adopters (*Managerial or institutional precondition*).
- Be attractive to use for certain applications in which the disadvantages of the new technology count less.

The social, technological–scientific, economic, and managerial (or institutional) preconditions are preconditions for regime shifts, already identified in the project “Technological Paradigms and Transition Paths” (Kemp et al., 1994). The fourth precondition is specific to the management of regime shifts through the creation and development of niches. Choice of technology implies a dilemma for SNM. To explore options for coevolution of technologies and their contexts, focusing on a specific technology is necessary but may lead to a bias in emerging patterns. Thus, SNM as transition tool rather than a market introduction strategy will have to allow for a variety of technological options and exploration of the options, while simultaneously working toward the embedding of at least one of them.

The Selection of the Experiment

In choosing an experiment, it is important to select a protected space in which the new technology may be used at relatively low cost and cause as little disruption and discomfort as possible. The space may be a certain application (for example, the use of solar cells for pleasure boats), a geographical area (a region or a city), or a jurisdictional unit. The heterogeneity of the selected environment means that there always are areas and types of application for which the new technology is attractive, in which the disadvantages count less and the advantages are valued higher. For example, electric vehicles (EVs) that do not emit pollutants at the point of use are attractive for the use in cities with high levels of pollution. The disadvantages of EVs, such as the low range and the recharging of the batteries, are less of a problem for fleet owners (taxi companies, utilities, public transport companies) than they are for consumers. Adding these two considerations suggests the use of EVs by fleet owners in cities as a societal experiment.

There is a second important element with respect to the choice of experiment: its conduciveness to (appropriate) learning. The users involved in the experiment should not have too idiosyncratic requirements. If there is too great a gap between the requirements of early users and the larger population of potential users, the technology may never reach the larger group. One of the reasons that electric vehicles never became a passenger car despite the wide use in milk cart fleets and golf carts is that the requirements of milk cart and golf cart users were completely different from the requirements of automobile drivers: range and speed and acceleration were not important, and technical change subsequently moved in a different direction,¹¹ using the internal combustion engine as the design for improvement. A related point about users is that users should also be critical, and able to communicate their requirements, so as to push suppliers to constantly improve the product.

The Set-Up of the Experiment

This is perhaps the most difficult step, as a balance must be struck between protection against and exposure to selection pressure. The choice of policy instruments can be based on the barriers that exist to the use and diffusion of the new technology. These barriers may be economic, as in when the new technology is unable to compete with conventional technologies, given the prevailing cost structure. They may be technical, in the form of a lack of complementary technologies, new infrastructure that is needed, or appropriate skills. And they may be social and institutional, having to do with existing laws, practices, perceptions, habits, and differences of interest. To deal successfully with these barriers, an integrated and coordinated policy is required. Possible elements of such a policy are: the formulation of long-term goals, the creation of an actor network, and the use of taxes, subsidies, public procurement, and standards. The policies should not attempt, however, to overcome all the barriers, making life too easy for the new technology. It should also be noted that the success of the experiment in terms of the original project goals is less important than setting interactive learning processes in motion and building new relationships between interdependent actors.

Scaling Up the Experiment

The next step concerns the scaling up of the experiment by means of policy. Even a highly successful experiment may require some kind of support from

¹¹We owe this point to Robin Cowan (personal communication, 1998).

public policymakers, especially in the case of environmentally benign technologies (whose benefits are undervalued in the marketplace). Again this raises the question of how far governments should go in the support of a particular technology, and whether they should bear part of the costs or let others carry the costs. It also raises the issue of complementary policies that would underpin and reinforce SNM; for an exploration, see Schot, Elzen, and Hoogma (1994) and Schot and Rip (1997).

The Breakdown of Protection

The final step is the phased breakdown of protection. Support for the new technology may no longer be necessary or desirable when the results are disappointing and the prospects dim. Breakdown of protection is also needed to introduce full selection pressure and to reduce windfall profits. The breakdown is best done in a controlled, phased way in order not to cause heavy problems for the companies involved.

Experiences with wind power technologies and policies can be interpreted in terms of our discussion of SNM. We will examine two questions. First, to what extent can the policies be seen to conforming to the idea of SNM? And second, what is the usefulness of SNM in the light of the aforementioned policy experiences? For example, could some of the problems and setbacks encountered in the process have been prevented through SNM? Regarding the first question, the policies indeed can be seen as attempts to stimulate the development of new technology by protecting it temporarily from the myopia of the market. Both in California and Denmark, a technological niche was created by government policies, although the way in which it was different in each place. In California, protection was much stronger, with investment subsidies of 50% in the 1980–1985 period (in addition to guaranteed electricity rates), compared to 20% to 30% in Denmark. In Denmark, wind turbines were controlled through an accreditation scheme, there were also siting, capacity and ownership regulations. Buy-back rates were introduced only in 1984 at levels above those in California. The rates were not set by the government but the outcome of negotiations between utilities and private wind turbine owners.

Looking back, one might say that in California there was too much protection and too little control. The protection was also of an adversarial kind, being based on capital cost instead of performance. The government had little influence on both the microeffects of noise and visual intrusion and macrooutcomes of total capacity that was installed. According to Cox et al. (1991), the high number of wind turbines that resulted from the wind program was well above the number needed to develop the technology. A policy along the lines of SNM could have prevented this. Common sense might

have achieved the same thing, but this would miss the important point that the Californian wind power policy was not specifically designed for wind power. The tax credits and PURPA requirements applied for all kinds of alternative energy sources—wind power just happened to obtain the greatest advantage from them. The Danish policies followed the scheme of SNM much better, by gradually phasing out protection and by focusing on learning and adaptation. This led to much better results, although, as already noted, this owed a great deal to other factors. We also should be careful in portraying policymaking as an exercise in logic and intelligence; policies are the outcome of bargaining and compromise between societal actors and coalitions in a context of multiple goals, conflicting interests, and uncertainty. The policies toward windpower in California and Denmark were highly politicized; they reflected different political ideologies and concerns. In the United States, the encouragement of renewables and cogeneration coincided with the political drive to break the monopoly powers of electric utilities. In Denmark, wind power was promoted on the basis of environmental benefits and the benefits of local self-sufficiency. In the United States, financial involvement from private investors was welcomed, whereas in Denmark such involvement was rejected by the public and by political parties. In Denmark, policymakers opted for a strategy of “controlled development,” for political reasons rather than economic energy policy reasons. The success of the Danish policy thus owed a great deal to political expedience. This does not make the approach of SNM less useful. In a political world, there is still a need for policy models to inform political choices.

In what ways could policymakers have benefited from the SNM approach? What lessons can we draw from the aforementioned policy experiences in the light of the SNM model, which emphasises the need of flexible decision making and experiments? Do they attest to the need of using SNM (or elements of SNM) for promising technologies? The experiences with wind power show the importance of finding a balance between protection and selection pressures. This is a continuing task for policymakers on which much of the success will hinge. Policies should be flexible and adaptive, aimed at correcting undesirable outcomes and amplifying desirable ones (where needed). To be able to do so, monitoring, practice analysis, and policy evaluation should be an integral part of a government support program. As to the policies, SNM emphasizes the importance of learning. The principal aim of technology introduction policies should be learning—learning about problems and how they may be overcome, how the technology may be integrated into the existing system, for what users the technology is attractive, for what purposes the technology may be used, how it may be sold, and so on. Learning is far more important than achieving high sales. There are even some advantages in small-scale projects; they are less costly and more

conducive to modification and change. Of course, small-scale projects do not help to achieve economy in production. But there is often more to be learned from a program lasting 10 years than a short program of 5 years that costs twice as much. Long collaborative projects also help to secure enduring collaboration to sustain a new type of development.

SNM also emphasizes that once the technology has been proved viable in the original domain of application, the scaling up of the user experiment or domain should be done in an ordered way. Jump starts will lead to inefficiencies, antagonism, and possibly obstruction by those who are harmed. Well-intended but ill-designed government support policies may very well harm the development of a new technology by giving the technology a bad reputation. In California, the sight of motionless wind turbines certainly damaged the reputation of wind power.

The setting of the experiment is also critical. Both in California and Denmark, locations were carefully selected on the basis of wind resource studies, but there were also some complaints about noise and visual intrusion that could have been prevented through the choice of different sites and the use of more silent turbines.

Finally, the breaking down of protection so as to subject the technology to normal market selection pressures; this may prove to be a difficult thing to do because of the investments that are made and the interests that have developed, and now press for continuation of the support program. The California program was expanded in 1984 for 2 more years despite the many problems and the downward revision of oil price predictions, which made wind power a less economical source of power.¹² The breakdown of support is best done in an ordered way so that firms get time to get used to the new situation by adjusting their business; again, the Californian policy stands out as a negative example.

REFLECTIONS ON SNM AS A STRATEGY TO CONSTRUCT TRANSITION PATHS

How far have we come in our attempt to develop a strategy to achieve regime shifts? One general point that structured our discussion deserves to be highlighted here: the strength of SNM lies in how it sets out to explore and exploit coevolution processes and patterns by reflectively intervening in them. Acting to create opportunities for learning, aligning goals and interests, shaping interactions—these are key features of SNM, features that will guide its further development.

¹²According to Cox et al. (1991), the wind power program could not be justified on economic grounds after 1983. Continuing the program to the end of 1985 resulted in an estimated cost of \$560,000,000 (in 1980 dollars) (Cox et al, 1991).

Thus, SNM is not just a useful addition to a spectrum of policy instruments. It is a necessary component of intentional transformation of regimes, multiactor processes in which government policy is only one component (although sometimes a decisive one). As a related point, SNM makes coevolution reflexive, perhaps creating new patterns for man to make his own (technological) history.

When SNM is specified in terms of “do” and “don’t” guidelines, its basic strength is converted—and to some extent betrayed or degraded—into a method that can be followed. Thus, it is important to always locate the method in relation to coevolution processes and patterns. One way to do this is to point out problems involved in following SNM as a management tool.

First, one must find a balance between protection and selection pressure. Too much protection may lead to expensive failures but too little protection may inhibit an interesting alternative path of development. This calls for ongoing monitoring and evaluation of coevolution processes and of the support policies themselves.

Second, there is no guarantee for success; changing circumstances may render the technology less attractive and technological promises may not materialize. Hence, it is important to promote technologies with ample opportunities for improvement, and with a large cost-reduction potential that can be applied in a wide range of applications. A technology that does not yield immediate benefits may still turn out to be a useful technology in the long term. This means that it is important to take a long-term perspective. For example, government support of electric vehicles has been criticized (e.g., Wallace, 1995) on the grounds that the environmental gains are limited and that their performance is poor compared to internal combustion vehicles. But this need not be true in a long-term vision, where electricity is generated by solar energy and advanced batteries become available. Improved batteries may also pave the way for hydrogen fuel-cell powered automobiles and the wider use of solar energy.

Third, it may be difficult for government to end the support for a technology because of the investments that have been made and resistance from those who have benefited from such programs—the “angry technological orphans” (as Paul David has called them) whose expectations have been falsely nourished.

And fourth, it is important undertaken as part of a long term transition strategy and program, to create sufficient momentum or critical mass. To date, most experiments with alternative transport technologies have been rather small and covered a short period of time. Experiments should be of sufficient size and time span to allow for learning economies and to bring about institutional change. There is also a danger that the knowledge that is accumulated in the experiment will be lost once the experiment is over.

By pointing out problems if the method of SNM were followed too mechanically, we developed, at the same time, further guidelines at a higher level, guidelines that require some assessment of the overall dynamics of the path dependency that is being created. What remains is the question of whether a regime shift will actually be achieved, and if the new regime will reflect the hopes of the strategic niche "managers." This question cannot be answered in a definitive way; the results of coevolutionary processes are not determinate, and there is no linear causality between specific actions and outcomes at the collective level, which would allow one to reason back from desired outcomes to purposeful action. On the other hand, some guidance is necessary in constructing transition paths in order to increase the probability that there will indeed be a transition, and that it will be in the right direction.

We cannot address these complex questions here, but it is clear that they have to be confronted in any strategy to achieve regime shifts. SNM is important in constructing new paths and path dependencies, but a further step is necessary. Our general analysis on technical regimes and transition paths provides an entrance point. The stabilization of technological regimes as rule sets implies a reversal from a situation in which rules are tentative and not constraining, to one in which the rules guide action and interaction, having an existence of their own, independent of the actors (and in a sense they have, because they are located at the collective level of a regime, and cannot easily be changed at the microlevel of individual action). Thus, a strategy to achieve a regime shift must also attempt to bring about such a reversal. Such strategies are well known (although not well analyzed) for the creation of industry standards. An example of unintentional reversal is visible in Arthur's (1988) analysis of competing technologies, where minor differences and contingencies may tip the balance and create irreversible advantages. Technological regimes encompass more than just industry standards and differential learning effects, so the situation is more complex. The basic phenomenon, of stabilization through reversal, is still the same, however. Approaches to effect such a transformation will have an opportunistic element of triggering new linkages and alignments (see Molina, 1993), of seeing and using opportunities to shift the balance. Understanding the dynamics and patterns of coevolution processes will inform the opportunistic actions and allow the introduction of some "method in the madness."

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