Time Strategies for an Innovation Oriented Environmental Policy

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1. Introduction
Environmentally friendly innovations have attracted public interest, because they are subject to far reaching expectations. They should deliver double or triple dividends not only in terms of ecological progress but also in terms of economic success and jobs. A main driver of that debate is the hope that environmentally friendly innovation will lower the economic burden posed on society in cases of transition from an unsustainable path of technological development to a more sustainable one.

The following approach is inspired by the idea that the timing of political measures is an especially important condition for the success or failure of environmental policy in bringing forth environmentally-friendly innovations. The basic hypothesis is simple: political impulses at the wrong time either barely bring about a worthwhile effect, or else they cost much money and time to cause a real change in economic behaviour. At the right time, even weak political initiatives can stimulate external environmentally-friendly innovations. We label such unstable phases of technological development as windows of opportunities.

To provide a first impression of this hypothesis’ meaning in the second section of this chapter, an example of a transition based on the set of case studies from SUSTIME project is presented. The case of chlor-alkali-electrolysis was selected because this example allows a comparison of different kinds of policies (Germany and Japan) and thus illustrates successful and unsuccessful examples of time strategies.

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Obviously there is a close link between the hypothesis above and the description of innovation processes by evolutionary economics. According to evolutionary economics, there are two types of innovation - incremental and radical. There are stable periods and revolutionary periods consistently in technical change. In the latter periods, the field of technological inquiry changes quite dramatically when there is a change in a technological paradigm, e.g. the engineering consensus of the relevant problems and approaches for solving them. Such periods are windows of opportunity for changing the direction of technological progress in quite a considerable way. The evolutionary framework underlying our concept of time strategies is described in the third section of this chapter.

The selection environment of technologies includes not only economic factors but socio-cultural and political factors, too. In the fourth section, the selection environment is broadened using the notion of co-evolution of different social subsystems.

The concept of a window of opportunity in time is crucial for our concept of time strategies. One might get the impression that time strategies of environmental policy are restricted by using a time window. On the contrary, governments often can contribute in preparing these windows. Sometimes it is even possible for governments to open a window of opportunity; such an attempt is labelled as technology forcing in literature. In the fifth section, time strategies of this kind are investigated in more detail.

Due to knowledge restrictions governments usually must face, the steering philosophy behind the concept of time strategies can not be a “press the button, get a particular result” approach. Since there is a close link between the concept of time strategies and the concept of transition management a few remarks concerning this connection in the last section conclude the chapter.

2. An Example – the Chlor-Alkali Electrolysis

One case study in the SUSTIME project was chlor-alkali electrolysis (for more details see Sartorius 2004). Basically three technological possibilities for chlor-alkali-electrolysis are available: mercury technology, diaphragm technology and membrane technology. If we delve further into the technical details, we find that membrane technology is the best one in ecological terms and - importantly - also in economic terms. The diffusion of this technology is considerably different in Germany and in Japan, however, as shown in Figure 1.

Figure 1: Diffusion process in Japan and Germany

![Diagram showing the diffusion process in Japan and Germany for different years and technologies (Mercury, Diaphragm, Membrane).]
The diffusion of membrane technology in Japan has been much faster than in Germany. To explain such a phenomenon, economists usually look for the economic incentives in terms of prices of products and costs of production processes. If we examine this case more closely, we find that the basic cause underlying this difference lies in the fact that the relationship between the membrane cell and the mercury cell process is characterised by the (temporary) lock-in of the established and the corresponding lock-out of the new technology. Due to the sunk costs associated with the established technology, the substitute technology can bring its economic superiority to bear only after those sunk costs are very low. This point was reached much earlier in Japan than in Germany. Beyond that, the lack of growth in chlorine production capacity in the 1980s and 1990s only allowed for a very limited number of new (membrane-based) plants to be installed.

Membrane cell technology in Japan took explicit advantage of the role of the government in first supporting the related R&D and then actively pursuing the phase-out of the mercury cell technology. In Germany, by contrast, in the search for a quick, yet incomplete reduction of the mercury emissions, the government preferred to retro-fit the existing facilities. As a result, this tended to decrease the chance of membrane cell technology in proving its superiority sometime in the future. The dominance of the old path was supported by a particular regulation scheme.

3. Technological Change in Evolutionary Economics

This above example can be used for a first generalisation. Obviously technological progress has its own momentum. Stable phases exist where we receive more from the same kind of technological progress. In unstable phases, a transition to really new technologies, system innovation or more radical innovations is more likely to occur.

The distinction between periods of rapid change and periods of slow motion is well known in evolutionary economics. Technological development is described as an interplay of radical innovations, sometimes called basis innovations, and incremental innovations. It is typically cumulative and patterned, with new branches growing from old ones. In order to describe this pattern Dosi has introduced the notions of “technological paradigm” and “technological trajectories”. (Dosi 1982). The notion of paradigm is borrowed from Kuhn. Along the lines of Kuhnian thinking, Dosi suggests the following definition: “... a technological paradigm can be defined as a 'pattern' for solution of selected techno-economic problems based on highly selected principles derived from the natural sciences” (Dosi 1988, 224).

The change from one paradigm to another can be labelled as a transition in the sense of Kemp and Rotmans who defined transition as follows:

“A transition
• is the shift from an initial equilibrium to a new equilibrium
• is characterised by fast and slow developments as a result of interacting processes
• involves innovation in an important part of a societal system.” (Kemp/Rotmans 2001, 6)

In addition to framing technological development with the belief system of engineers – as emphasized by the term paradigm used by Dosi - there is a broad range of factors which stabilise a given trajectory of a techno-economic system. Literature addresses these factors under the label of increasing returns of adoption. The most important factors are economies of scale, economies of scope,
sunk costs, learning effects and network effects (for a more detailed discussion of these factors see Sartorius/Zundel 2004).

Basically, economies of scale are due to the fact that the benefit arising from employment of more sophisticated machinery can more than outweigh its higher overhead cost if only the quantity of output is high enough. While production facilities at various output scales can well be based on different technologies, it is important to note that economies of scale are based on the technologies that exist respectively at any given point in time; learning does not play a role in this concept. Accordingly, economies of scale are basically measured on the firm level in terms of average unit cost as a function of output quantity per unit of time. On the other hand, economies of scale have the potential to stabilise monopolistic structures or, at least, to provide firms who realise them with a powerful competitive (cost) advantage. The latter point turns into a disadvantage for many kinds of potential market entrants, but it is particularly relevant for new technologies which, at the beginning of their life cycle, cannot draw upon their own or foreign experiences with (and thus cannot make use of) the advantages of large-scale production.

By taking into consideration a firm’s variety of production outputs, economies of scope - beyond the mere number of a firm’s distinguishable outputs – can account for the realisation of synergies between different production lines. This includes the common use of certain resources, intermediate products, or production facilities. In any case, it requires a high degree of coordination between the production lines within a firm. A prominent example is the coupling of production in the chemical industry. As in the case of economies of scale, the effect of economies of scope is two-fold. On one hand, it leads to and accordingly is measured in terms of a relative decrease in average production cost, as such representing a substantial increase in profits or, more generally, wealth. On the other hand, when compared with economies of scale, the complexity of interactions between existing production lines makes it even more difficult for a market entrant or a new technology to become competitive. For this requires that either comparable synergy effects must be realised in the first place or the degree of superiority of the new technology as such must be high enough to outweigh such synergy effects right from the beginning. The latter point represents a major obstacle for the competitiveness of a new technology. As such, a detailed analysis of the interactions giving rise to synergy effects - in addition to the mere cost aspects of economies of scope - is an indispensable part of all attempt to identify a possible techno-economic window of opportunity.

Although the first explicit mention of ‘learning by doing’ goes back to Arrow (1962), the cost decreasing effect of growing experience in designing, constructing, and using production facilities (‘learning by using’) has been a part of common wisdom in economics since Adam Smith. Unlike the cases of economies of scale and economies of scope, the cost-decreasing potential of learning by doing and learning by using is a function of the cumulative output of a given branch of production over the entire period of time since its introduction. The learning effects relevant in this context are equivalent to incremental technical progress and they are typically expressed as the percentage of cost reduction per doubling of the cumulative production output. While scale effects could, at least in principle, be realised at any point in time, experience effects are the result of an ongoing developmental process. As a consequence, learning effects provide any new technology with a large potential for further cost reductions. At the same time, however, they require every investor into such a technology to subsidise its output until the cost of the respective product will have become competitive. Depending on the initial cost difference, this may explain the occasional need for an extensive, long-term investment effort.
Investment in a new, process or product-related, technology can cause significant sunk costs if this investment renders useless an old technology prior to its complete depreciation in the absence of the new technology. Schumpeter refers to this innovation-induced early depreciation as ‘creative destruction’. Technological spillovers from other firms employing the same (old) technology significantly contribute to these sunk costs. For every firm that intends or is forced to carry out a change in its technological regime, sunk costs represent opportunity costs of the new technology (and, equivalently, negative externalities of the old technology). It is evident that in such a situation, a firm will substitute a new technology for an old one only if the return to investment in the new technology outweighs both the expenditure into the new capital and the sunk costs associated with the old technology.

While the scale and learning effects described above give rise to positive externalities on the supply side, network externalities refer to the fact that the utility derived by the users from the use of a given technology is positively correlated with the total number of users. The telephone network is a typical example. Alternatively, a technology can be subject to network externalities if it does not itself constitute a network, but relies on and is compatible with another technology that forms the network in its turn. The dependence of the internal combustion engine on a network of filling stations can serve as an example here.

Increasing returns of adoption do not last forever. One important reason for this appears to be that the problem-solving capacity of a dominant technology (the body of knowledge) is exhausted. Marginal returns within any given technological paradigm tend to decrease. This has been worked out by Windrum following an argument by Frencken and Verbart (1998). Windrum writes that “the functional form of the relationship between learning and the number of adopters is sigmoid. As the number of contributors increases in the initial phase of its history, so the problem-solving capacity of the user network supporting that technology increases exponentially due to gains of the division labour and benefits from arising of new fields of application. However, there is an upper limit to the problem-solving capacity of a user network. As a technology paradigm matures, so co-ordination costs start to outweigh the gains derived through further division of labour (…). The ability to identify and develop new fields of application is similarly limited…” (Windrum 2003, 302). Therefore increasing returns of adoption are at some point bounded from above, a necessary but not sufficient condition for technological change.

Real markets (niches) represent a further important condition because they facilitate processes of learning (about technology, the market, social acceptance) and processes of societal embedding (capital formation, setup of distribution, dissemination of knowledge, user-side adaptations to facilitate the adoption, gaining of user acceptance, removal of regulatory benefits etc.) that are necessary for the further development of a new technology or technology system (Kemp/Rip/Schot 2001). They help to create virtuous cycles that allow a new technology to emerge, by helping the technology to overcome initial barriers of high costs, the non-availability (or high costs) of complementary technologies and misfits between the new technology and the external environment during the infancy period of a new technology when it has not yet benefited from dynamic scale and learning economics.

If a new technology competes with old paradigm technologies we label this competition “old/new”. If there is a new function which must be fulfilled and more than one technology is involved, the technology competition is a “new/new” one. Environmental regulation of pollutants, for example, can force completely new technologies without any predecessors. In other words, a new function has to be established. Examples are filter technologies which cannot be replaced by integ-
rated technological solutions for technical reasons or because of high opportunity cost.

Based on this difference, we also can distinguish between two kinds of windows in the techno-economic system. Following the investigations of Kemp (2001) concerning old/new competition we can refer to the first one as an old/new window. This window is open if the investment cycle of old technologies comes to an end and new promising technologies are available at that time. Following the investigations of Arthur (1989) and David (1987) referring to new/new competition, we can refer to the latter one as the “Arthur-David-window”.

This window comes into being in the early stage of competition between similarly far developed technologies. In principle, the economic competition between two new technologies is governed by the same forces as the competition between an established and a new technology. The main difference consists in the points of departure of the respective races. Due to the positive feedback mechanisms involved, even small differential effects accruing soon after the start of the competition are more decisive for the outcome of the race than larger effects some time later. Evidently, time matters more here than in the competition between old and new technologies. If unstable phases of technological development arise, then even so called “small historical events” (Arthur) can frame the continued direction of technological development. This phenomenon is often observed in the software programme market in which many company strategies are based on the idea of being the first to occupy the market and to erect market entry barriers through network effects. The case of Microsoft is a well known example of such a strategy. In unstable phases, appropriate timing is clearly an important factor for success.

Stable phases of technological development caused by a combination of small historical events and feedback mechanisms described above are addressed in the literature by the notion of path-dependency (Arthur 1994). Path dependent technological developments can bring about a lock-in of a dominant technology and correspondingly a lock-out of other possible technological solutions. In cases of unsustainable development, lock-ins create a development trap that has to be overcome by environmental policy. Before examining the details of this problem, we should touch upon the selection environment outside the economic system.

4. Broadening the Selection Environment

Variation and selection mechanisms of technologies are not restricted to the economic sphere. The selection mechanisms include not only selection by product markets. Selection is a “multi-dimensional phenomenon” (Windrum 2003). It includes selection of visions of future developments by capital markets. Selection takes place when new technologies must be adjusted to the existing technologies with which they must be combined. The existing infrastructure at a given point in time has a selective effect; private standards and public regulation work like a filter. Additionally, social concern and political mechanisms have an impact in the sense of a selection process. Stability and instability in the corresponding co-evolving systems can have a great impact on the evolution of given techno-economic system. They can both reinforce and destabilize each other.

In giving this interplay a more precise meaning, we can simplify and distinguish between three social subsystems only: the techno-economic system, the socio-cultural system and the political system. Each system is partly determined by its own dynamics and partly by the interaction of the systems. The distinction
between stable/unstable has its specific meaning based on the system to which it refers.

Public concern in the socio-cultural system is a main driver of environmental policy. We say that the socio-cultural system is stable with respect to the technological path in question; this is if the public is indifferent about the sustainability of this path and no real interest by mass media can be observed. The socio-cultural system is considered unstable if a growing concern arises in scientific communities about the ecological performance of the dominant technologies and a public debate can be observed in mass media.

Assigning possible states to the political system is slightly more difficult. Two features of this system are important: First, the system cannot be completely separated from society. In democratic societies, policy reacts – as it should – to public interests. On the other hand, the political system is not completely free in adapting public interests; it has its own institutional and social momentums. These mechanisms operate like a filter and influence whether and to what extent external impulses are picked up by political actors and are transformed into political concepts and actions. Against this backdrop, a three-part distinction of possible states of the political system is useful:

- The political system is open if its endogenous mechanisms are stable and do not impede external impulses for change.
- The political system is inert if its endogenous mechanisms are stable and impede external impulses for change.
- The political system is unstable if its endogenous mechanisms operate in favour of an external impulse for change. We refer to this constellation as a political window of opportunity.

The classical idea of the ideal sequence found in economic textbooks is as follows: sustainability problem is detected, public awareness arises, pressure is put on the political system for action, an internalisation concept is implemented in the economic system, and in the end the sustainability problem is (hopefully) solved. The sequence starts with an impulse for change in the socio-cultural system and ends with a successful internalisation in the techno-economic system. One alternate situation is when the impulse for change begins in the socio-cultural system and brings about changes in the techno-economic system without any political influence. In this case, public discourse indicates a demand for change, which can be transferred by smart innovations into private willingness to pay for new and ecological better products. The demand for high-quality food or the demand for textiles not treated with chemicals are examples of this, despite policy support in spreading these products in the meantime. This illustrates that there are many starting points for change and the classical constellation described above is only one among them.

For the limited space of this chapter it is not possible to describe the factors which stabilise or destabilise the socio-cultural system and the political system according to the techno-economic system (for more details see Nill 2002 and Sartorius/Zundel 2004). However, it is hoped that new, environmentally friendly technologies can arise if time windows in the techno-economic subsystem, the political subsystem and the social system are ordered in an appropriate manner (see also Nill 2002). This idea is explored in a more systematic way in the following section.
5. Time Strategies

"There is no guarantee that evolution, whether in nature or in the economy, will be beneficial." (Witt 2002, 13) Since there is no balancing mechanism between problem generating and problem solving abilities of technology progress, keeping society on sustainable paths will always be a political business, even if one admits that policy often fails in running that business successfully. The example in section 2 shows that policy can make a difference.

If a given techno-economic system brings about serious impacts on the environment - that is, it is non-sustainable - we can say that this system is not very well adapted to the environment in the evolutionary sense. A successful adaptation depends mainly on four different abilities of markets:

- the ability to adopt new insights out of the scientific system (discovery function of markets)
- the ability to generate a diversity of new promising solutions which are feasible in a technical sense (research function of markets)
- the ability to improve feasible solutions to competitive ones (development function of markets), and
- the ability to select the best solutions among the competing ones (selection function of markets).

Policy is well advised to use these abilities especially if a particular path of development is not sustainable, but these abilities do not automatically work in the direction of sustainable development. In case of a development trap on an unsustainable path, particular functions of markets are underdeveloped in relation to what is needed for a sustainable development; the main target of policy is improving these abilities for generating new and ecological better solutions. We refer to this approach as second order sustainability, which is an improvement of particular abilities of markets depending on time (see Sartorius 2003).

In principle, second order sustainability aims at an intelligent use of market forces: in particular the ability to create new environmental solutions that are low-cost and the ability to select the best ones through market competition. The relative importance of these different abilities or functions for new and better paths of technological developments based over time depend on and vary with the kind of competition (old/new and new/new) and the status of the techno-economic system (stable/unstable). Thus a strategic framework is required to take these distinctions into account.

In order to link strategies to possible combinations of states of different social subsystems and to develop a taxonomy, we use the idea of a sequence, beginning with an old path and the discovery that this path is not sustainable and no promising solutions are available from the outset. The sequence ends when a transition is completed and one new technology has taken over. It should be emphasised that it is not suggested that the complete sequence or a sequence in exactly that order must be carried out. Very often there are repeated attempts of transition in reality. It is also possible that government should not interfere, since the autonomous development of the techno-economic system tends itself to be an unstable situation. The following table provides a survey of time-critical situations.
With respect to the notion of window of opportunity we can assign the following names to the strategies, described above:

- **Window preparation**: enhancing diversity and solving development problems in the pre-market stage (1, 2)
- **Window opening**: technology forcing (2.a)
- **Window utilisation**: making a transition easier (3, 3.a, 3.b)
- **Window closing**: reviving selection function of markets (4)

In the following paragraphs these strategies are explained in more detail.

(1) The first situation can be characterised by three features: a sustainability problem linked to the old path is detected, the old path is stable, no techno-economic window exists and no promising solutions are available. The main target needed to improve flexibility of the techno-economic system is stimulating the development of promising solutions mainly by supporting scientific research and providing incentives to firms to adopt new scientific ideas.

(2) If promising solutions are already available we can proceed to the next step. The second situation is characterised by a stable old path, but now there is at least one promising solution. The main targets needed to improve the flexibility of the techno-economic system are creating diversity and stimulating firms to develop at least one competitive solution, for example by organising learning curves. Government should make best use of market forces; here this involves mainly searching for new promising solutions and developing new solutions until they become competitive to some extent. Expectation management is important for policies that prepare the emergence of future techno-economic windows. Weak signals such as long-term targets also might play a role. Mechanisms may include e.g. the creation of niches for or the support of new alternatives (strategic niche management). Additionally, we must keep in mind that environmental policy requirements might also hinder window emergence, e.g. delay investment cycles (retrofitting), thereby increasing sunk costs especially if end-of-pipe treatment is involved. In this case transition might be obstructed by environmental policy itself.
A situation very similar to (2) arises if strong social or (international) political pressure forces the government to open a window using political means under the conditions that the old path is stable and only promising solutions are available. This situation is different to that described under (2), because the government has to deal with strongly opposing market forces. Although this may be necessary we must be aware that the danger of add-on-technologies or retrofitting of existing technologies increases considerably, especially if governments use instruments that stimulate quick fixes. Governments have an incentive to do so if the political window of opportunity is shorter than the time period required for developing more fundamental alternative solutions. In addition to the targets mentioned in (2) government must balance the social pressure for a quick solution needed for political support and the time period needed for more far-reaching solutions.

If more than one solution becomes competitive to some extent, the next step can be taken. This situation may be generally characterised by the following features: the old path is unstable or at least a techno-economic window can be anticipated, and there is competition between different new solutions. At least one of the new solutions is competitive in principle. In short, we face a combination of new vs. new competition and old vs. new competition. Fundamentally a transition is now possible and the government’s target might be to facilitate this transition, for example by abandoning discriminating mechanisms for the new solution.

In some cases the situation is more complicated than in (3): besides the competitive solution there are other solutions that are merely promising and have not yet attained competitiveness. The development of their potential can be strongly impeded by simply following the target of transition. If some new solutions can use network effects and early economies of scale, they can gain an advantage, and cannot be overtaken by other promising solutions with a possibly greater potential. In other words, there is a trade-off between diversity and facilitating transition. In this situation the government must keep the window open by suppressing the selection function of markets until the most promising solutions have developed their potential. If this is too costly or not feasible and the old vs. new window can only be used by the more advanced technologies, at least a lock-in of new solutions must be avoided, e.g. through reservation of niches etc. An example is provided by the photovoltaic case study. It is clear that photovoltaic will not be competitive in the foreseeable future compared with conventional power plants; it will not be implemented when the conventional power plants have to be replaced by new power plants. Photovoltaic technology is not a real alternative in the next window of opportunity. Despite this, it makes sense to keep this technological option alive over the next years.

Sometimes the necessity of a transition is possible due to internal limits of the old path. As a result, new vs. new dynamics come to the forefront. For policies which take advantage of, or utilise, these new vs. new techno-economic windows, “utilise” can also mean “keep the window open” for a sufficiently long time. Political responsibility is also high here: environmental policy may act as the “small historical event” within the selection environment important for the increasing returns models, e.g. biases competition. This may reinforce or even lock-in first mover advantages. The political exploitation of techno-economic new vs. new windows consists mainly in assuring that in an open phase of competition the best technologies in ecological and economic terms have a chance of being selected.

The key question to be solved now is whether dynamic allocation efficiency gains can justify the losses of static allocation efficiency by suppressing the selection function of markets. If no further technological progress of new technologies can be expected, the main target in this situation is a proper selection of best avail-
able solutions. This sometimes means that government has to end all political interference in market processes. This step is important because subsidies, protected markets and other political support create their own momentum; they bring about sunk costs and create many vested interests when support ends.

The simplest order may be when windows in all three systems exist simultaneously. In contrast, a transition is more difficult if time windows in the social and the political system do not accompany a techno-economic window. The empirical findings of our case studies in the SUSTIME project support this idea. In all cases, we observed favourable conditions in the social and the political system; these are listed under the heading “window utilisation” and can be regarded as success cases (for more details see Sartorius/Zundel 2004).

In addition, the case studies demonstrate that success conditions must be complex depending on the time strategy used and how radical the transition should be. Technology forcing by political means in a stable phase of the techno-economic system is much more demanding than a transition in an unstable phase. What we learn from our case studies is that technology forcing can only be executed successfully if a sufficient and long term public pressure exists, conditions in the political system are favourable and promising solutions are available and adopted by influential firms. This coincidence of events seldom occurs, and this is likely the reason why politically induced radical transitions are seldom observed in reality. The conditions for incremental changes are far less demanding and this is perhaps the reason why these changes form the usual pattern of environmental policy aiming at technology changes.

The role of promising solutions is very prominent in many case studies. Promising solutions are often decisive for transition, because the public perception of promising solutions brings about considerable support for political attempts in transition through new regulation schemes. A promising solution shows that a transition is feasible, sometimes at low costs, and is therefore probably the most important factor of a politically induced window preparation. These findings completely correspond with our idea that a transition is more likely to occur when more alternative solutions are developed.

6. Conclusion

Time strategies are not an academic artefact; timing problems are ubiquitous in environmental policy. One might think of the phase-out of nuclear power plants in Germany or of the broad range of political measurements in supporting regenerative energy sources. Timing is important in almost every important case of environmental policy. This is not an accident, since path dependent developments of technological change are also widespread. Thus environmental policy should be well advised if political measurements are embedded in a strategic framework as described above.

Information is a scarce resource for political actors when choosing an appropriate time strategy depending on the state of the techno-economic system. To time their measures well they must know the state of techno-economic system, they must distinguish between theoretical ideas, promising solutions and competitive solutions; they must also know whether the potential of a promising solution has been explored and when public support of these will end. The widespread opinion in literature is that political actors are not well informed about these features of technological development and we agree with this opinion. Obviously such a knowledge base for policy is far beyond reach. However, what is possible is pattern prediction in the sense of Hayek (1969); what is certainly impossible are
prediction of the outcome of technological development. Mainly for that reason the approach of time strategies must be understood in the sense of guiding lines of a transition management, by which political action under the condition of uncertainty is addressed.

By emphasising the limits of knowledge of political actors, many scholars allege that political actors are free in choosing a generic or a selective approach of technology or environmental policy, and that they should choose a generic approach since such a policy is far less demanding based on knowledge limits. Due to path dependency, however, even generic measures such as taxes or tradable permits often end up being selective depending on time of implementation. In a stable phase generic measures mainly bring about further improvement along the boundaries of dominant technologies; in an unstable phase generic approaches can - but not always - bring about more fundamental changes of technological changes. In taking this for granted, political actors often have no real choice between a generic and a selective approach. Empirical finding bear out this claim to some extent; almost every regulation scheme has a technological content discriminating against some technologies and supporting others. In light of this background, the real question is how far should - and can - political actors improve their knowledge base, while admitting that they face severe restrictions in doing so.

A learning-based adaptive approach developed by the concept of transition management (Kemp/Romans 2001) might be an appropriate way for handling the severe knowledge restrictions with which environmental policy is confronted.

References


