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**CONTENTS**

<b>Editorial</b>	
B.R. Martin, Keeping plagiarism at bay—A salutary tale	905
<b>Erratum</b>	
H.W. Gottinger, Retraction notice to 'Estimating demand for SDI-related spin-off technologies' [Res. Policy 22 (1) (1993) 73–80]	912
<b>Original Articles</b>	
M. Järkeläinen, M. Maula and G. Murray, Profit distribution and compensation structures in publicly and privately funded hybrid venture capital funds	913
J.E.L. Beccoviz and M.P. Feldman, Fishing upstream: Firm innovation strategy and university research alliances	930
J. Edler and L. Georgiadi, Public procurement and innovation—Resurrecting the demand side	949
D. Abdo Higón, The impact of R&D spillovers on UK manufacturing TFP: A dynamic panel approach	964
N. Gil, On the value of project safeguards: Embedding real options in complex products and systems	980
U. Schmoch, Double-boom cycles and the comeback of science-push and market-pull	1000
B. Nooteboom, W. Van Haverbeke, G. Duysters, V. Gilsing and A. van den Oord, Optimal cognitive distance and absorptive capacity	1016
C. Gonzalez-Brambila and F.M. Veloso, The determinants of research output and impact: A study of Mexican researchers	1035
R. Svensson, Commercialization of patents and external financing during the R&D phase	1052
M. Miozzo and A. Bonaccorsi, Co-evolution of physical and social technologies in clinical practice: The case of HIV treatments	1070
A. Hommels, P. Peters and W.E. Bijker, Techno therapy or nurtured niches? Technology studies and the evaluation of radical innovations	1088
F.W. Geels and J. Schot, Comment on "Techno therapy or nurtured niches?" by Hommels et al. [Res. Policy 36 (7) (2007)]	1100
A. Hommels, P. Peters and W.E. Bijker, Reply to Geels and Schot	1102

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# Techno therapy or nurtured niches? Technology studies and the evaluation of radical innovations

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## Abstract

This article contributes to recent discussions in technology studies about applying insights from technology studies to policy decisions about the development and management of technological innovations. It does so by examining two approaches that can be used by policy makers to manage radical technological innovations in mobility and transportation: strategic niche management (SNM) and the PROTEE approach. The SNM approach uses protective ‘niches’ to develop radical innovations, whereas the PROTEE method is grounded in the assumption that technological innovations have a better chance of success if made “vulnerable” by subjecting them to risks and oppositions from the outset. Both SNM and PROTEE have, so far, been applied to retrospective case studies. This paper examines their potential effectiveness in the monitoring of real time innovation projects by comparing their conceptualizations of ‘learning’ and ‘experimenting’. It argues that the two approaches can draw upon each other to achieve a more refined conceptualization of learning and experimenting and in dealing with the problem of change and obduracy in the development of innovation projects.

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## 1. Introduction

Explaining the success or failure of new technologies, practices, artifacts, and regimes is a central concern of technology studies. Over the past 20 years STS scholars have studied technological innovation from a variety of

perspectives. Their concern has been largely to examine the technical, economic, social, cultural and political contexts of innovations. The question addressed in this article is if and how knowledge about technological innovation can be made relevant to communities and organizations interested in developing policies for promoting innovation. In this paper we argue that it is crucial to know how knowledge about successful technological innovations can be used to determine the potential success or failure of the development of new technological innovations. A second related question we address is how these insights can be effectively translated into tools for technology policy making.

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In the 1990s, the policy relevance of technology studies became an explicit issue on the STS research agenda (Rip et al., 1995; Sørensen and Williams, 2002). Several attempts were made to turn insights garnered from STS studies into instruments for monitoring innovation processes. Several approaches were developed including strategic niche management (SNM), bounded sociotechnical experiments (BSTE), constructive technology assessment (CTA), the multi-level perspective, the MIA approach and PROTEE. We will examine two of these approaches: strategic niche management and PROTEE.

Strategic niche management was developed by scholars at the universities of Maastricht, Twente and Eindhoven during the 1990s. It is a policy tool aimed at concrete intervention in innovation processes. The PROTEE approach was developed in a project under the EU fourth framework programme, in a collaboration between the University of Maastricht, Brunel University (UK), the center for the sociology of innovation (CSI) in Paris, and a number of industrial partners active in developing new intermodal systems for freight transport (Technicatome, Krupp, ZIV, Mondragon systemas). PROTEE became further refined in the SOCROBUST methodology (Jolivet et al., 2003) and in the MIA approach (Maatschappelijke inbedding analyse: societal embedding analysis) (Kets and Mourik, 2003).<sup>3</sup>

Innovations are traditionally divided into two types: radical and incremental. Incremental innovations are considered those which result from the development or refinement of existing technologies. These tend to be relatively easy to manage. In contrast, radical innovations prove much more uncertain and risky and are therefore more difficult to manage. Because radical innovations are at the core of many research programmes in the public sector and their financial consequences can be huge, it is important to develop innovation management tools for them. Both SNM and PROTEE attempt to take up this challenge.

Strategic niche management (SNM) is defined as the “creation, development and controlled break-down of test-beds (experiments, demonstration projects) for promising new technologies and concepts with the aim of learning about the desirability (for example, in terms of sustainability) and enhancing the rate of diffusion of the new technology” (Weber et al., 1999 p. 9). The SNM approach consists of a number of overlapping phases (Weber et al., 1999). It starts by identifying a promis-

ing new technology or concept and by thinking about the implications, advantages or disadvantages in broad terms of the new technology. Second, an experiment has to be designed. The new technology will be tested in a controlled experimental set up in which the initiators of the experiment decide about the actors that must be involved in the experiment, and the protective measures that must be taken in order to ensure its development. The third stage consists of implementing the experiment. The SNM approach identifies this stage as the most difficult (Weber et al., 1999) because it is at this point that an experimental innovation encounters problems. The problems which can bar successful implementation may be technological as well as economic, social or institutional. The aim of this stage is to learn what kind of problems arise during an innovation’s implementation so that technologies, social practices and mobility assumptions can be adjusted. During the fourth phase, the innovation process is scaled up from a single experiment to a niche, and is then integrated with relevant activities going on elsewhere. The fifth and final phase is concerned with the evaluation of the level of protection of the niche. The protection is usually removed after the experiment is completed, but sometimes it is removed during an experiment. The decision whether to continue or cut an experiment is made during this stage.

PROTEE is designed as a real-time management tool for evaluating the quality of ongoing technological innovation projects. Its approach consists of an iterative process in which an innovator and an evaluator engage with each other. The interaction between innovator and evaluator has the form of a socio techno therapy. The innovator gives a description of a project’s risks based on the evaluator’s PROTEE-checklist. The checklist consists of the four classes of indicators.<sup>4</sup> The evaluator must elicit a risky description of the project using these indicators as questions in an interview. Each indicator can be assessed on a scale of 1–5. After a couple of weeks or months the ‘therapeutic’ session is repeated. The innovator gives another description of the present state of affairs in the innovation project. The evaluator then compares

<sup>3</sup> Kets and Mourik (2003) tried to link the MIA-approach and transition management.

<sup>4</sup> The four classes are called realism, strategy, falsifiability and innovativeness. Examples of indicators (within these four classes) are: how much opposition do the innovators take into account? How diverse and independent are the trials to test the various aspects of the project? Is the project learning from its environment? For more details, we refer to the final report of the PROTEE project (*PROTEE final report (EU 4th framework)*, 1999). See <http://europa.eu.int/comm/transport/extra/web/downloadfunction.cfm?docname=200310/protee.pdf&apptype=application/pdf>.

the two descriptions, assigns a grade and by this process assesses the quality of the learning curve.

Both SNM and PROTEE have, so far, been applied to retrospective case studies. STS scholars have used both PROTEE and SNM to study innovation processes in transport systems.<sup>5</sup> PROTEE has been used in studies of innovations in freight transport, such as the building of a fully automated container terminal (see below), the construction of new freight handling systems and the implementation of a new transport and freight centre. SNM has been used for studying personal mobility technologies, in particular, electric vehicles, car sharing systems, sustainable public transport and traffic management systems. It is interesting to see that most analyses using PROTEE and SNM are done *ex post*, whereas both are usually presented as real-time monitoring and in the case of SNM, forward looking. Both approaches put strong emphasis on experimenting and learning processes.<sup>6</sup> Although experimenting and learning are interpreted differently in the two approaches, both approaches emphasize that the primary goal of experimenting in innovation processes is to increase the ability to learn about these processes. Learning can apply to learning about the technical aspects of an innovation, but also to learning about its social environment, the user context, relevant government policies etc.

Despite sharing a focus on learning and experimenting, the two approaches differ in crucial ways. In the first place, the two models differ in their objectives: SNM wants to achieve a more sustainable society by stimulating sustainable technologies, whereas PROTEE aims at optimizing learning processes of, in theory, all kinds of technology. Secondly, there are important differences in the theoretical underpinnings of each approach. SNM draws on evolutionary economic approaches to innovation, constructive technology assessment, and sociohistorical studies of past transformations. PROTEE draws on general STS studies of innovation processes and uses concepts from actor network theory and SCOT. Recently, some attempts have been made to merge the fields of STS and evolutionary economics.<sup>7</sup> Interestingly, Russell and Williams (2002) see SNM as an

example of “the fruitful interaction of sociological and evolutionary economic ideas” (Russell and Williams, 2002 p. 45).

In this article we examine these two models in more detail. We will begin by describing the key elements of the SNM and PROTEE approaches and the theoretical assumptions underlying them. The observation that the political goals of the two models differ crucially results, for instance, in different criteria for the success of the interventions made in the innovation process. Moreover, we claim that the theoretical assumptions underlying them are based on different views of the structure of experiment. In the SNM approach, experimenting is understood as creating a controlled space, a ‘niche’, in which most contingencies can be ruled out. In contrast, in the PROTEE approach, it is precisely the continuous confrontation between innovation and contingency that constitutes the experiment and ultimately determines an innovation’s success or failure. Since both approaches underscore the importance of learning processes for the realization of technological innovations, we will also evaluate the potential of each for improving the quality of the learning processes entailed in technological innovation trajectories. Finally, we will discuss the implications of using models like SNM and PROTEE for policy development.

## 2. Developing innovation in protected spaces: strategic niche management

SNM is geared to deal with innovations that are likely to contribute to a regime shift. A typical example of such a shift is the move from the existing energy system based on non-renewable (fossil) energy sources to a more sustainable energy regime based on biomass.<sup>8</sup> By focusing on transitions to a more sustainable society, the SNM approach has a clear political goal. In the SNM approach, an innovation process is considered

<sup>5</sup> Work in SNM has also been carried out in the areas of energy and waste water. PROTEE is claimed to have a wider applicability.

<sup>6</sup> The same applies to BSTE. BSTE also views experiments as possibilities to learn and is less aimed at intervening in the innovation process than SNM and PROTEE (see Brown et al., 2003).

<sup>7</sup> See for instance Geels (2004). According to Russell and Williams (2002) evolutionary economics (EE) and the social shaping of technology approach are largely compatible: “their preoccupations overlap strongly and their findings are often consistent” (p. 44). There are, however, important points on which social shaping theorists (SST)

remain critical of evolutionary economics: EE focuses too much on the macro/meso level and fails to acknowledge and explain diversity and contingency in innovation processes (p. 44). It tends to overlook the detailed dynamics and outcomes of a particular innovation process. Furthermore, EE tends to treat local learning processes as black boxes. Russell and Williams argue that the SST approach is better equipped to address the detailed mechanisms involved in innovation. However, “we should not expect a complete merging of the two bodies of theory: their agendas and concerns are different, and they have strengths at different levels of generalization” (Russell and Williams, 2002 p. 45).

<sup>8</sup> See Rob Raven’s PhD thesis (2005). Another example is the regime shift from the car system based on the electric combustion engine to a car regime based on more less polluting energy sources such as electricity.

successful when it results in what is called a ‘regime shift’. Since the aim of SNM is primarily to achieve regime shifts which contribute to a more sustainable society (Hoogma et al., 2002), the implementation of new, more sustainable technologies is crucial. In the SNM approach, new technologies are ideally developed in protected spaces or niches. However, Hoogma et al. concluded in a recent study that many of these innovations are never adopted. It turns out to be very difficult to implement technological innovations outside the niche in which they were developed, which is what led Hoogma et al. to the disappointing conclusion that “we were certainly too optimistic about the potential of SNM as a tool for transition” (Hoogma et al., 2002 p. 195).

The success of early niche development is measured by two criteria according to Hoogma et al. (p. 28): the quality of the learning processes and the quality of institutional embedding. Hoogma et al. propose a broad concept of learning that involves learning about the technologies, but also learning about users, societal and environmental impacts and government policy. Institutional embedding means that in the process of development from niche to regime, a kind of network is built to support the innovation. This network includes complementary technologies and infrastructures, but also a number of supporting actors (e.g. users), guided by a shared set of expectations.

SNM is based on evolutionary economics, which strongly influences its model of change. Its model of change is based on the notion of path dependence, the classic example of which is the QWERTY-keyboard.<sup>9</sup> The change in technological regimes is explained by referring to actors who have a stake in searching for incremental solutions that can be achieved by improving the dominant technology. It makes economic sense for them to stick with the dominant technology because there are many investments (in terms of money but also users skills) made in that technology (Geels, 2002). It is interesting to note that issues of path dependence are temporarily set aside or put between brackets in the SNM approach: “In the niche model, lock-in and path dependency assumptions are relaxed. Various technological options can co-exist over a long period, precisely because of the existence of niches requiring other functionalities” (Hoogma et al., 2002: 26).

This line of reasoning becomes clearer when we relate the SNM approach to the use of path dependence and lock-in in the so-called “multi-level perspective”. The “multi-level perspective” distinguishes three levels in technological development, diffusion and implementation of innovations (Geels, 2004). The micro-level is the level of niches and the meso-level is the level of “technological regimes”.<sup>10</sup> According to Rip and Kemp,

“a technological regime is the rule-set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artifacts and persons, ways of defining problems—all of them embedded in institutions and infrastructures” (Rip and Kemp, 1998 p. 338).

In contrast to the niche level where the rules are not yet stable or clear, in regimes rules have become stable and have more structuring effects on the activities performed in the regime (Geels, 2004). At this level, change becomes more difficult to achieve as the regime limits the development of alternatives that do not fit into it. Moreover, because regimes are structures, individual actors have difficulties changing the rules that form its basis (Rip and Kemp, 1998).

The macro-level is the so-called “sociotechnical landscape”. The metaphor of landscape puts stress on the obduracy of any given society’s material and immaterial makeup. Landscapes consist of material environments, shared cultural beliefs, symbols and values. They are difficult to change because “landscapes are beyond the direct influence of actors, and cannot be changed at will” (Geels, 2004 p. 913). It is interesting that the more we move to the macro-level, the greater the acknowledgement of constraining factors and resistance to change is.<sup>11</sup> This means that the potential for flexibility and change are linked to the level of niches, whereas embeddedness and resistance to change enter the model at the meso-level of regimes. This implies that at the level of niches, obduracy of sociotechnology is hardly taken into account. This explains the optimism about the potential for change in much of

<sup>9</sup> The QWERTY-keyboard was developed in the era of mechanical typewriters as a solution to the recurrent interference of adjoining keys. In the period of personal computers and electronic keyboards, however, this arrangement no longer seemed necessary, and alternative designs were made. None of these, however, became widely accepted.

<sup>10</sup> The concept of technological regime in the multi-level perspective is a broadening of Nelson and Winter’s concept: “Regimes are a broader, socially embedded version of technological paradigms” (Rip and Kemp, 1998: 388).

<sup>11</sup> This can be restated by referring to Thomas Misa’s argument that the more we move to the macro-level of analysis, the more we are inclined to take a technological determinist point of view (Misa, 1988).

the SNM literature.<sup>12</sup> Part of the constraining mechanisms that play a role in the ‘selection environment’ are at least temporarily ignored. This is different in the PROTEE approach where no distinctions between levels are made. Here, PROTEE’s roots in ANT become clear: distinctions are the result of learning and innovation processes but cannot be distinguished *a priori*. It is interesting that in recent SNM-literature, a too strong distinction between these levels (e.g. between niche and regime) has been criticized (see e.g. Raven, 2005).

### 3. Innovation management as a socio techno therapy: the PROTEE approach

The PROTEE model is designed for innovation projects of which the outcome is uncertain and unclear. Managing these kinds of technological innovations is difficult because the uncertainties surrounding them prevent the use of conventional management tools to measure risk and the probability of success. This raises the question of whether such projects can be managed at all and, if so, how. PROTEE is limited to procedural indicators only. The key feature of PROTEE is that projects are not evaluated according to costs, feasibility, social acceptability, plausibility, coherence etc., but only through the quality of the procedure used to *learn more about* costs, feasibility, social acceptability etc.

The starting point of the PROTEE approach is a ‘learning pact’ between the innovator and a PROTEE-equipped evaluator. The evaluator uses a checklist that contains a number of questions that are meant to make the innovator aware of mistakes that are typically made in developing innovations. Drawing on STS case studies, the PROTEE approach has identified four basic reasons for the failure of technological innovations:

- (1) *Lack of realism*: This class criticizes technological innovations that are seen as ballistic: passing from non-existence into existence without taking the context into account. This class makes the innovator aware of different degrees of uncertainty in his or her project, which, if recognized, can lead to alternative paths.
- (2) *Lack of strategy*: This class criticizes the inability of innovators to take into account various forms of resistance to a project. This class urges an innovator to learn about (potential) opposition to a project and anti-programs.<sup>13</sup> Anti-programs are human or non-human entities whose behaviour may put the success of the project at risk.
- (3) *Lack of falsifiability*: This category criticizes the practice of innovators to avoid circumstances in which their accounts of the project could be reliably falsified. The trials to test a project’s development must be representative and critical. This class of indicators makes the innovator aware of ways to test critically the evolution of a project.
- (4) *Lack of innovativeness*: This class criticizes the practice of stopping innovation projects because they are too risky (hopeful monsters) and of fostering projects that are not worth continuing (hopeless pets). This category makes it possible to distinguish between hopeful monsters and hopeless pets.

A relationship between an innovator and an evaluator is established in the process of evaluating a project according to these four classes of mistakes. The two engage in a learning process to analyze and discuss the project in PROTEE terms. The comparison of the indicators over time makes it possible to establish the quality of the learning curve. The evaluator makes sure that he or she avoids the four classes of mistakes in technological innovation in order to maximize the chance of navigating the project through its development. An explicit indicator is formulated against each mistake. To avoid the four classes of mistakes, means that the learning process will be optimal. In the end, innovators and evaluators have to reach a common definition of the project to decide over its prolongation or ending.

An important feature of PROTEE is that it attaches a great deal of importance to processes of learning and experimenting. PROTEE seeks to enable an innovator and an evaluator to establish a ‘learning pact’ which enables the quality of the learning process to be assessed. The project is conceived as a learning process, aiming

<sup>12</sup> It is interesting to note that SNM and “multi-level approach” studies appear to diverge on the optimism they express in relation to the possibility of achieving change. On the one hand, Geels stresses that as long as there is a stable regime, radical changes at the level of niches cannot be expected. Transitions come about when dynamics at the three levels link up and reinforce each other (Geels, 2004). On the other hand, Kemp et al. (2001) quite optimistically focus on the *opportunities* the regimes and landscapes create for sociotechnical change. This difference in expectations can perhaps be explained by the context of their research. Geels studies historical cases, whereas those of Kemp, Rip and Schot are more policy-oriented. In a policy context – aimed at transforming our society into a more sustainable one – a more optimistic view of the possibilities to achieve change definitely sounds more productive.

<sup>13</sup> On anti-programs, see Latour (1997).

at the progressive discovery of the context in which the innovation becomes or will be embedded. It is assumed that neither the innovator nor the evaluator begins in a state of knowledge: they do not know how to realize a technological innovation. That is why they have to learn. Learning is applied to all relevant variables in an innovation project: learning about clients, risks, costs, social acceptance, etc. This implies that multiple learning curves can be distinguished in any given project, each of which is related to the different variables that are in play in an innovation process. The PROTEE approach does not accept innovators who always give the same description of a project, because doing so implies that the learning curve has not begun. In this respect, PROTEE differs from traditional policy tools in which the repetition of the same presentation is taken as an indicator of the robustness of a project.

PROTEE defines a successful innovation trajectory as a process in which learning is maximized. As a consequence, we have to redefine success and failure: for PROTEE, a failed project is one that does not learn. If it is impossible for anyone involved in the project to learn about its context, its opponents, its redefinition, or the trials necessary to judge it, if the same smooth description is always given, then the project should be stopped. These starting points feed back on the definition of innovation in the PROTEE approach. PROTEE characterizes innovation by taking risks under uncertainty, with a lack of knowledge. If a less risky choice is made, less can be learnt and thus PROTEE will be less capable of improving the learning curve. PROTEE not only focuses on the technical parts of projects but also on innovations in usage, control, accounting, law, as well as pieces of machinery or composition of existing machinery (*PROTEE final report (EU 4th framework), 1999*).

In contrast to SNM, the PROTEE approach is geared primarily towards maximizing the learning capacity of an innovation project rather than the adoption of new (sustainable) technology on the grounds that the better the learning curve of a project is, the more chances it has of survival in the real world. The way PROTEE works in launching technological innovations differs from SNM. Instead of initially protecting innovations in niches, PROTEE deliberately focuses on the vulnerabilities of the innovation process: it stimulates innovators to focus on those aspects in the innovation process that are difficult, risky or likely to fail.

Having discussed the key features of both approaches, we will now compare their strengths and weaknesses and their (in)compatibilities in relation to two themes: (1) the underlying notions of the structure of good experi-

ments (Section 4) and (2) the different ways in which both models relate learning processes to sociotechnical change (Section 5).

#### 4. Experimenting: making innovations vulnerable or protecting them?

One of the first theorizers of the innovation process, Joseph Schumpeter already stressed the importance of vulnerability for innovation (Schumpeter, 1942). He recognized that the fundamental instability of the capitalist system always presented opportunities for entrepreneurs to engage in innovative enterprises. In doing so, Schumpeter identified vulnerability, seen previously only as a state of instability and uncertainty, as a positive and necessary prerequisite for innovation (Bijker, 2006). Accepting Schumpeter's claim as a precondition of innovation, we argue that one of the key differences between the two models is their conception of the relation between an innovation and its context. In the SNM approach, radical innovations are initially developed in protected niches after which they are confronted with the 'real world outside'. The PROTEE approach takes the opposite trajectory and begins the development process by trying to make any given technological innovation vulnerable, with the aim of maximizing its learning capacity.

SNM advocates that innovations be developed in protected niches or 'nurtured spaces' (Hoogma et al., 2002). A variety of policy instruments are then used to protect them, e.g. government subsidies, partnerships, or policy interventions. Niches form a nurtured space for the generation of radical innovations. Niches offer a basis for their further development, for new development trajectories, and for the transformation of regimes. Kemp et al. (2001) stress that the SNM approach was originally developed to increase the chances of a new technology's successful introduction. Later the approach became part of a broader framework whose aim was to build new technological regimes and to create possibilities for regime shifts (Kemp et al., 2001: 270).

However, according to Hoogma et al. (2002), one of the issues that is still partly unresolved is how niche protection should be organized and how the gradual reduction of protection can be carried out without disrupting an innovation's development. Hoogma et al. argue that forms of protection available locally may not be enough. They claim that a more intensive form of protection accompanied "by sponsors and accompanying measures that change the overall frame conditions for economic decision making" is necessary (Hoogma et al., 2002: 202). They acknowledge however, that one of the disadvantages of such intensive forms of protec-

tion is that niches can act as prisons (Hoogma et al., 2002: 171). This phenomenon helps to explain why it is so difficult for an innovation to become adopted once it has left its protective niche. A number of empirical studies using the SNM approach have confirmed this observation. It is striking that the planned top down experiments described by Hoogma et al. (2002) (the Bikeabout project, ASTI and Praxitèle<sup>14</sup>) failed, whereas car sharing, as a newly emerging experimental business, was the most successful in developing outside the niche. Another example of a retrospective SNM-experiment is the PIVCO electric vehicle developed in Norway. The new vehicle received a lot of protection from some of Norway's major industries and the government. However, when the protection was removed and the vehicle was tested outside its protective niche, the public did not accept it. Moreover, the circumstances created in the niche were so typically Norwegian that the concept could not be transferred to other countries (Hoogma et al., 2002; Weber et al., 1999).

Another example is a project to develop electric vehicles on the German island of Rügen. In October 1992, a testing and evaluation project of electric vehicles began in Rügen which lasted 4 years. Sixty EV's equipped with new battery systems were tested by more than a hundred users. The project was subsidised by various German states and municipalities. Hoogma et al. stress that without a subsidy provided by the German federal research ministry covering nearly 50% of the project's costs, it was unlikely that the car manufacturers would have initiated the experiment. The results of the experiment were disappointing. According to Hoogma et al. "the contribution of the Rügen project to the development of the electric vehicle niche was very limited with respect to both learning and institutional embedding" (Hoogma et al., 2002 p. 71). Learning was limited to technical issues, such as the testing of new types of batteries. And although the environmental benefits of the project (both in terms of lower noise levels and less pollution) were clear, the manufacturers were not prepared to arrange a follow-up to the project even though it was recommended by the project manager. The number of EV's on Rügen in 1996 was a bit more than at the start of the project in 1992, but it clearly did not contribute to further niche development, as Hoogma et al. claimed. Despite these disappointing results, SNM pro-

ponents did not conclude that formal experiments have less potential for SNM. They admitted, however, that it is important to think about "the trade-offs between an open setting (which facilitates learning) and tight control (which closely steers the experiment)" (Weber et al., 1999 p. 37).

The difficulty experienced in SNM with the societal embedding of innovations after niche conditions have been removed can arguably be explained by the conceptual underpinning of the SNM approach itself. SNM is based on an evolutionary model of technological change in which variations are developed within niches and selection takes place within a selection environment. The approach thus assumes a rather clear distinction between a technology and its context. Only in the third phase of an SNM process (see above), is an innovation confronted with its selection environment, and actors begin to think about possible opposition to the project. After a niche has been successfully established, the 'real' selection environment still has to be confronted, because the niche only partially reflects, 'reality'. In this respect, it is salient that Hoogma et al. (2002) concluded that the projects they studied were "overly self-contained". This can be the result of the experimental set-up in niches, which forms the cornerstone of the SNM approach.

Whereas SNM rests on the assumption that technology and its context can be (temporarily) separated the PROTEE approach opposes this idea. The key innovation of the PROTEE approach (and here it differs most from other approaches to managing innovations) is that it deliberately tries to make an innovation vulnerable by confronting it as much and soon as possible with the 'real world'. The means of achieving this are based on eliciting a set of risky descriptions—descriptions, made by the innovator, in which uncertainties, opposition, and alternatives to the present development trajectory are made explicit. Normally, policy makers want to make sure that a project they fund will be described in the 'smoothest' possible way. Innovators will 'by nature' start with a persuasive description of their projects. In the PROTEE approach, it is a contradiction of terms to say that a technological development is an innovation and to give a description of it in which all the issues that may jeopardize the future success of the project, are left out. Therefore, acknowledging the potential vulnerabilities of any given project is a very important feature of PROTEE, and that encapsulates exactly what we mean by a risky description of the project. By "vulnerability" we do not mean only that a project should be open to criticism, but also that any criticisms of it needs to make vulnerable in advance key features of the project in order to anticipate future critical developments.

<sup>14</sup> The Bikeabout project started in the early 1990s in Portsmouth, UK as an experiment to set up a bicycle pool. The accessible sustainable transport integration project in Camden, UK ran between 1994 and 1997 and involved the development and implementation of a number of electric and natural gas powered minibuses. Praxitèle was a French project to stimulate individualized public transport with EV's.

An example of a technological innovation that has been analyzed (retrospectively) using the PROTEE approach is the automation of the Delta-Sealand terminal in Rotterdam's harbour between 1982 and 1993.<sup>15</sup> Berghoff et al. have argued that the Delta-Sealand terminal represents a fundamental innovation in container transshipment (Berghoff et al., 1993). The terminal's automation entailed four innovations: (1) transporting containers with automated guided vehicles; (2) stacking containers with automated stacking cranes; (3) a computerized operating system; and (4) a number of changes in the organization of labor.

According to some PROTEE indicators, the innovator, Europe combined terminals (ECT) – one of the world's largest stevedores – learnt a lot during the project's first stage, which lasted from 1982 to 1986. ECT wanted to build an automated terminal and was looking for customers. It broadened its network and thought strategically about the various actors that would be needed to build the terminal. When Sealand entered the scene as a potential customer, ECT was flexible enough to offer four different terminal designs. In other aspects, however, the learning process was less successful: it is unclear how much attention ECT paid to possible anti-programs. The risk of sealand withdrawing from the negotiations was clearly identified, but other risks were not considered. By PROTEE criteria, this neglect of potential risks is considered a bad sign.

In a later stage, which took place between 1987 and 1992, less was learnt in this project: there was a clear choice for one terminal design, and the layout of the project as a whole had become somewhat inflexible. The technical specifications of the terminal, agreed upon by sealand, had to be met at any cost. During this stage of the project, the PROTEE approach was less useful as a tool for managing technological development because the project had more or less stabilized, the uncertainties had diminished and less was learnt.

One major weakness in the PROTEE approach is that it remains unclear how to decide between the stabilization of a project when an innovation proves successful or to stop an innovation's development because the innovators do not learn anymore. When does the relevance of the PROTEE approach end and when does it become more useful to use other technological management tools? At a certain moment, the uncertainty in a project diminishes, the degree of innovativeness of a project declines, and less is learnt. Then PROTEE is not useful any longer,

but it is difficult to assess precisely when this moment occurs. This is perhaps comparable to the difficulty in SNM to determine when niche conditions can be safely removed. We think, however, that the risk of 'a niche becoming a prison' can be solved by confronting the innovation with 'the real world outside' in an earlier stage. Interestingly, it can be argued that the experiments described in Hoogma et al. can be considered successful according to PROTEE criteria if one looks at how much has been learnt during some of the experiments.

## 5. Learning: conceptualizing processes of sociotechnical change

It is clear that SNM, like PROTEE, aims at achieving an enhanced reflexivity among actors involved in innovation processes. STS scholars have argued that when the SNM approach is used, actors will acquire a better understanding of the nature of technological change and the dilemmas that might arise in managing it. Learning is a key concept in the SNM approach as well. In SNM, learning is broadly conceived as learning about technical specifications, the user context, societal and environmental impacts, industrial developments and government policy and regulatory frameworks. Hoogma et al. (2002) distinguished between first order and second order learning in the SNM approach. First order learning means that, in a niche, actors learn about how to improve the design of a technological innovation, which features of its design are acceptable for users and ways of creating a set of policy incentives that will facilitate its adoption. However, second order learning is needed for the establishment of a regime shift on the basis of niche development. In second order learning, conceptions about technology, users, demands and regulations are not tested, but questioned and explored. This is called "co-evolutionary learning" (Hoogma et al., 2002: 29). Successful niche development consists of first order learning on a whole array of aspects coupled with second order learning.<sup>16</sup>

The process of learning is much more operationalized in PROTEE than in SNM: learning indicators are defined and the whole technological innovation management instrument is designed to be able to assess the quality of the learning curve. At the same time, both approaches assume that optimal learning processes increase the chances of an innovation's successful implementation. However, the definition of a successful innovation process differs in PROTEE and SNM. For SNM, success

<sup>15</sup> For a detailed analysis of the process of designing and building the delta-sealand terminal in Rotterdam, see Bijker et al. (1999).

<sup>16</sup> Hoogma et al. (2002) conclude, however, that first order learning is far more predominant in the experiments they studied.

consists of the creation of niches for an innovation, an innovation's development and ultimate diffusion. For PROTEE success is defined as the achievement of an optimal learning process.

How does learning lead to sociotechnical change in both approaches? As mentioned above, the SNM approach is heavily based on the notion of path dependence. Social constructivists describe “trajectories” or “paths” as being actively constructed or destructed, instead of being given by nature (Garud and Karnøe, 2001). This approach seems to have been adopted by SNM theorists as well. According to Kemp et al., “SNM is a method for constructing paths” (Kemp et al., 2001: 270). However, one of the problems of models of path dependency is that they usually ignore the role of agency.<sup>17</sup> Crude notions of path dependence and trajectories as developing according to an internal, “natural” logic have been criticized by STS scholars, who emphasize the contingent and fluid character of technological development. The sociologist of technology Trevor Pinch has correctly pointed out the “a-symmetric” use of the notion of path dependence by economists, who only invoke history when addressing “inferior” technologies. In contrast, Pinch proposes a more constructivist variant that focuses both on the paths taken and alternative paths not taken (Pinch, 2001). It is precisely because the SNM approach starts with a clear conception of the end-result of an innovation (that is: a sustainable technology) and temporarily shields this conception in niches from the ‘real world’, that the possibility of alternative paths which arise as a result of learning processes are ruled out.

Whereas in the SNM approach, an innovation seems to be taken as more or less “ready made”, the PROTEE approach considers any innovation as constantly “in the making”. PROTEE clearly starts from different assumptions about the relation between learning and sociotechnical change. Because PROTEE begins from an interaction between an innovator and an evaluator, the actor perspective<sup>18</sup> is much more visible in this approach than in SNM. PROTEE, which is based on sociological and anthropological approaches to understanding tech-

nological innovation such as SCOT and ANT, focuses on the work that the actors must do to achieve change. In contrast to SNM, learning in the PROTEE approach means opening up the possibility of alternative paths.

More specifically, in the PROTEE approach, a class of indicators is directed specifically to the problem of obduracy and the possibility of developing alternative “paths”. This class of indicators (called strategy) focuses on the degree to which innovators take possible opposition to their project into account: “the innovator should be able to describe the project by populating the world with as many opponents (human and non-human) as possible. The first thing to test is the absence or presence of anti-programs, that is, of entities etc., whose behaviour may jeopardize the project” (PROTEE manual, test version: 13). Secondly, the innovator must be able to describe his or her project from the point of view of its opponents. The innovator should be able to give “good reasons” why they might oppose the project. Third, the innovator must have a clear view of which aspects of the project are negotiable with opponents and which aspects that are not. Finally, the innovator must make sure that his project is flexible enough to incorporate opposition in the project's design. The project must be able, in other words, to “absorb” as much opposition as possible (PROTEE manual, test version).

The Delta-Sealand terminal case illustrates the PROTEE approach. In the beginning of the project some anti-programs were identified. For example, the main customer of the terminal, sealand, would drop out of the negotiation process. In the early stages of the terminal's development (1982–1986), the project was learning from its environment in the sense that the terminal design was put forward as a way to solve the problem of social unrest in the Rotterdam harbor and the perceived expansion of container transshipment in the near future. In a later stage, organizational anti-programs were identified. In operational tests of the new terminal, it turned out that some of the crane drivers did not operate the cranes in the way that software engineers had expected. PROTEE's aim is to make innovators think about such obstacles from the start of their projects.

The point where the PROTEE and SNM approaches can learn from one another becomes clear when we describe the results of the Rügen case. Importantly, the actors who challenged the conventional wisdom about car manufacturing, small car manufacturers, critical scientists or environmentalists, were excluded from the project. Users were involved only in the testing phase and excluded from the design and setting-up phases of the project. Hoogma et al. (2002) suggest that if such opposition to the project would have been taken more

<sup>17</sup> For a review of critiques of the notion of path dependence see MacKenzie and Wajcman (1999). The critique comprises two claims: (1) it is not clear, but often disputed what the “best” technology is (maybe the alternatives to QWERTY are not superior); (2) if a technology has an existing alternative that is seen as better by many, it is unlikely that the “inferior” technology will survive, since there are many strategies (e.g. subsidizing or offering it below costs) to overcome the lock-in context of the “inferior” technology.

<sup>18</sup> On the importance of an actor perspective in designing mobility projects, see Peters (2006). Smith et al. (2005) also argued that ‘agency’ should play a more important role in regime transformation models.

Table 1  
Comparison of the two models of innovation management

	PROTEE	SNM
Disciplinary foundations	STS, SCOT, ANT	STS, evolutionary economics
Political objective	No explicit political objective	Political objective is aimed at realizing a specific path (towards sustainability)
Criteria of success	Optimal learning process (leading to a surviving technology)	More sustainable technology (leading to a more sustainable society)
Experimental method	Making innovations vulnerable (by socio techno therapy)	Initial protection using 'niches', gradual removing of niche protection
Key mechanism in innovation processes	Integration of innovation and context from inception, role of obduracy, embeddedness	Distinction between variation and selection environment, path dependence
Related tools	Socrobust, MIA	CTA, alternative technology (AT), multi-level approach

seriously, the niche development process might have been more successful.<sup>19</sup> If, indeed, PROTEE would have been applied in the Rügen case from its inception, the innovators might have been more aware of the critical (f)actors hampering the project.

In sum, because of its theoretical roots in evolutionary economics, SNM's model of technological change is closely linked to the notion of path dependency. PROTEE, having its roots in SCOT and ANT, is based on notions as obduracy, actor perspectives and embeddedness. Because in the SNM and "multi-level" approaches the role of constraints to innovation processes is limited to the macro- and meso-levels of development, we have argued that PROTEE offers more explicit ways of dealing with opposition to a project and takes the obduracy of technology more seriously. On the one hand, it is understandable that path dependence is so central in SNM, considering SNM's political goal. Path dependence (e.g. of a sustainable technology trajectory) can be very positive in innovation processes. A clear advantage of the SNM approach in this respect is that, by focusing on path dependencies and institutional embedding, this model has a clearer idea of how to stabilize an (desirable) innovation. In the PROTEE approach it is less clear how and when to reach 'closure' in the development of a radical new technology. Furthermore, PROTEE might be subject to the critique that an actor oriented approach assumes that it is always clear which actors are involved, what their roles are, and that the whole process can be shaped by the actors at will and without much attention

for structural factors. Although the PROTEE model is not intended to be voluntaristic, a clearer focus on institutional embedding, as in SNM, can clarify this issue.

## 6. Conclusion: policy implications of technology studies

This article examined the SNM and PROTEE approaches to managing technological innovation by describing their key elements and the theoretical assumptions underlying them. An overview of the main differences between PROTEE and SNM discussed in this article is provided in Table 1.

We acknowledge that the two approaches must be tested in real time innovation projects to be able to evaluate them properly. The aim of this article is not to state which of the two models is 'best', but to discuss their strengths and weaknesses. Both approaches have a very rich understanding of learning in innovation processes, in which a great variety of elements can be subject to learning: technical aspects, but also user aspects, legal issues, or financial facets. An interesting feature of SNM is that it makes a distinction between first order and second order learning. However, learning is much more operationalized in PROTEE. The interactions between evaluator and innovator in PROTEE are aimed at establishing the quality of the learning curve. It is less clear how the quality of the learning process is analyzed in the SNM approach. Moreover, in PROTEE, learning has a clear temporal dimension: the quality of the learning process can change over time. In SNM, this aspect of the learning process is unclear. Furthermore, 'learning' in the PROTEE model acknowledges the important role of barriers to sociotechnical change and obduracy of sociotechnology. Underestimating the factors or actors that constrain radical change makes the SNM model perhaps less capable of dealing with the problem of obduracy. Moreover,

<sup>19</sup> Hoogma et al. describe four EV experiments. Apart from the PIVCO and the Rügen cases, they studied a project in La Rochelle, France. In this case, the EV sales were ultimately disappointing because electric vehicles for private use could not exist without special protection. Another EV-experiment in Mendrisio, Switzerland contributed mostly to niche development because it was able to create a positive image for EVs.

a conception of obduracy that is mainly based on the notion of path dependence (as in SNM) keeps innovators unaware of other mechanisms involved in the construction of obduracy.<sup>20</sup>

In terms of their policy relevance, both approaches have something different to offer.<sup>21</sup> The SNM approach is related to a clear political agenda in the sense that striving for a more sustainable society is its main goal. This can only be achieved by starting radical innovations out in protected niches. PROTEE, on the other hand, does not have such a political goal. This lack of normative engagement is a consequence of its underlying theoretical perspective in which a desired outcome is, deliberately, not stated beforehand. In theory, PROTEE can be thus used to monitor all kinds of radical innovations. Whether the PROTEE-innovation process contributes to a more sustainable society can only be assessed retrospectively and is not the starting point.

The policy relevance of PROTEE is that it offers insights into the learning capacity of innovation projects and tentatively helps to determine when a project should be stopped or continued. However, PROTEE is disappointing in not yet being specific and clear enough as to when this moment occurs. Here PROTEE might benefit from a closer focus on mechanisms of institutional embedding that form a necessary part of successful niche developments. By limiting its focus to learning processes only, the process of technology stabilization and acceptance might become overlooked. In this respect, PROTEE can learn from SNM: a focus on processes of institutional embedding and path dependence may result in more stable technologies.

We thus conclude that SNM and PROTEE can learn from one another in achieving a more refined conceptualization of learning and experimenting and in dealing

<sup>20</sup> See Hommels (2005). Other mechanisms are the role of dominant frames, embeddedness and persistent traditions. These mechanisms play a role at the micro-, meso- and macro-levels of technological development.

<sup>21</sup> This exploration suggests that some of the assumptions underlying the PROTEE approach, unexpectedly and interestingly, are closely related to recent debates in policy analysis on deliberative governance (Hajer and Wagenaar, 2003). Considered from a PROTEE perspective, policy experiments would no longer possess a strategic character which focuses on the desired end result of a policy decision, but instead would outline the procedures and principles that could enhance the quality of the learning process which would lead to that outcome. The outcome of the process would be the object of debate and criticism. This means that the end result of a policy experiment can be completely different from what actors expected it to be at its inception. We believe that our exploration of these two models could be a next step in the investigation of the relevance of technology studies for the debate on deliberative governance.

with the problem of change and obduracy in managing innovation projects. It will perhaps be difficult to reconcile the two approaches with respect to the more fundamental distinction in experimental set-up: the difference between nurturing innovations in niches and putting them to the test in a socio techno therapy. This latter approach makes innovators immediately aware of the broader context of their innovations instead of postponing its relevance to a later stage of an innovation's development. By initially protecting innovations in niches, as in the SNM approach, there is a risk that the gap between the innovation and the real world in which it must be implemented becomes too large. However, a diminishing of the distinction between niche and regime as proposed in recent SNM literature (Raven, 2005), opens opportunities to bring to two models closer to one another: in this way the difference between initially protecting innovations in niches and making them vulnerable from the outset becomes smaller.

We think that the development of policy tools like SNM and PROTEE in technology studies can be fruitful for both STS and the policy arena.<sup>22</sup> Our exploration also shows how the two models, one based on an evolutionary model of technological change and the other on a constructivist model, can learn from one another. Apart from bringing the notions of learning and experimenting closer, it would be fruitful to further explore conceptual connections between notions as path dependence and obduracy and between actor perspectives and institutional embedding.

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<sup>22</sup> In this sense we agree with Sørensen and Williams (2002) who argued that technology studies can help to broaden the agenda for technology policy.

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