Managing Breakthrough Innovations:
theoretical implications from - and for - the sociology of science and technology

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Presentation to the 2003 ASEAT Conference Knowledge and Economic & Social change: New Challenges to Innovation Studies (Manchester, April 7-9)

1 Introduction

This paper considers the distinctive challenges of managing 'breakthrough' or 'disruptive' innovations. There are numerous well-established methods for assessing and monitoring research and development investment. Familiar techniques for calculating risks and uncertainties or for evaluating the relative merits of competing projects make all kinds of assumptions about the stability of technological, regulatory and market environments. Yet these are precisely the dimensions that are uncertain, fluid and difficult to anticipate when dealing with innovations that by their nature challenge existing technological conventions and regulatory frameworks and that imply a reconfiguration of relations between consumers and producers.

How are managers to proceed strategically or to make informed judgements in these inherently uncertain situations? We begin by reviewing a range of 'classic' responses to this problem. Taking a different route, our aim is to work with more sociologically informed theories of innovation and detail their relevance for managing 'radical' projects, that is projects that are uncertain because of the 'breaking through' on which their success depends. Accordingly, we build on the insight that 'robust' innovations are those that are effectively 'embedded' in society. Recognising that every technological choice is simultaneously a social choice we work through the implications of the point that the embedding of technological innovation is not a matter of 'end-of-pipe' acceptance. It is, we argue, created in the same movement as that which shapes the objects, processes or services in question. In short, a breakthrough innovation's capacity to find its way in society is co-constructed through and during the tests and trials that it undergoes. This is of practical significance for the dynamic monitoring and management of such projects.

In operationalising these ideas some points are obvious. Rather than anticipating external events, as is usual when making scenarios, the challenge is instead one of articulating and rendering visible the 'script' of the future world already implied by the positioning of the project/innovation-in-the-making and the choices of those who manage it. What assumptions are being made about the world beyond the project or firm, and are they well founded? What must the world be like in order that the breakthrough innovation 'succeeds'? In addition, how does the development process itself modify such ambitions and assumptions?

Again building on insights from science and technology studies, we underline the importance of following the progressive testing of innovations-in-the-making as they are encountered, debated and rejected or naturalised across a more or less extensive range of social contexts and fora. From this perspective it is not necessarily useful to conceptualise development as a sequence of standardised stages (e.g. concept, pilot, prototype, etc.). In keeping with sociological studies of innovation, it makes better sense to equate the 'state' of a breakthrough innovation to the technoeconomic network that supports it (and that is at the same time changed through the developmental process).

This is all very well in theory, but can we go a step further and turn these somewhat abstract observations into practically useful management tools? In describing and reflecting on the

results of the SOCROBUST project, a project designed to do just that, we reach a number of conclusions. Some relate to the limitations of the very ideas with which we chose to work. Others concern the political and institutional contexts in which risky projects are managed. Our analysis of innovation and hence of the means by which it might be managed led us to devise and advocate techniques and methods that would, if adopted, challenge 'normal' ways of working. However sound and 'rational' the proposed approach, its implementation requires an unusually 'open' - even experimental - style of management and a correspondingly unconventional view of failure. We argue that this rift between theory and practice constitutes a significant challenge for innovation studies.

The paper begins by reviewing contemporary advice regarding the management of uncertain, risky and radical innovation. The next part draws on a different set of intellectual resources, revisiting theories of innovation and considering what is involved in the successful societal embedding of novel technologies (and associated practices). Building on these ideas, the fourth part describes the design of a workable method that project managers might use when managing risky projects. The final section looks back at what the experience of designing such a method revealed, first identifying some of the problems involved in putting concepts from science and technology studies to work and then reflecting on the organisational environments in which risky projects are managed and in which methods like SOCROBUST might and might not be put into practice. This forces us to attend to the politics as well as the theory of innovation management.

2 Managing uncertain, risky and radical innovation

Throughout, we focus on means of increasing the chances of socio-economic success for radical or 'architectural' innovations, that is for projects the realisation of which would involve technological discontinuity and/or breakthrough in terms of the definition and delivery of products or services. Our argument is that this type of innovation (which often represents around a tenth of the R&D portfolio in a large established firm) cannot be managed in the same way as 'on-going', 'incremental', 'sustaining' or 'continuous' innovations which 'build a gradual accumulation of useful variations' (Cooper, 2000). Where innovation is incremental, comparison between competing projects can be based on calculations of risk, such as estimated return on investment. By contrast, radical projects face such great 'uncertainty' (while often having far greater potential) that the application of traditional forms of evaluation is at best a formal game. This class of projects requires a different style of management. Some analysts (e.g. Colarelli O Connor, 1998) go so far as to say that 'sound management practices for the development of incremental improvements may well be detrimental to the development of discontinuous, breakthrough innovation'.

This opening paragraph raises a host of further questions: what is meant by uncertainties? How can we know when 'normal' forms of evaluation are no longer relevant? What are the conditions under which meaningful calculations *can* be made? And when these conditions do not apply, on what grounds should sponsors and funders then base their decisions?

Although Bower and Christensen (1995), Courtney et al (1997), Colarelli O Connor (1998) and more recently Hamel (2000) have all underlined the significance of 'breakthrough' innovations in securing the long-term future of firms, only a few authors have addressed these problems head on. Following Abernathy and Clark's (1985) analysis of the emergence of dominant designs, there is some agreement about the sequence of events involved. The initial years are, for example, expected to be ones of 'technological ferment' when the technology remains 'fluid', when actors undergo 'technological experimentation and competition' and in which there is a substantial 'rate of product variation' (as 'alternative forms compete for dominance') until 'a dominant design emerges as a synthesis of a number

of proven concepts'. This is associated with 'the emergence of product-class standards' (Tushman and Anderson, 1986).

But the question remains: how can firms manage such situations? One solution is to take a different approach to the management of incremental as compared to radical innovation. Various authors — not many, and most of them only recently — have tried to analyze how established firms have succeeded in making radical breakthroughs.

This retrospective work has generated a number of conclusions. One is that the managers of radical projects require specific capacities and capabilities. Chen and Van de Ven (1996) speak of a 'charismatic leader' with enough 'imagination to create a new vision which narrows attention and rallies unity out of diversity'. Tushman and Reilly (1998) write about 'ambidextruous managers' characterised by 'relatively long tenure' and the will to be 'constantly striving to renew themselves'. Collarelli 0 Connor and Rice (2001) add that the individuals they label as 'opportunity recognizers' must have 'boundary spanning capabilities'. Other often complementary conclusions relate to the organisational features believed to foster the management of breakthrough innovations. As Collarelli O Connor and Rice explain, those who draw such conclusions often do so without explaining how conducive environments might be engendered in practice. Differences of detail aside, such analyses have one attribute in common: they focus on project management and the environment in which projects are monitored or evaluated.

Further effort has been invested in analysing the wider environment and constructing scenarios with which to anticipate and estimate the chances of success. The following table itemises some of the factors that are thought to influence the diffusion of high-tech products and that are routinely incorporated in scenario making.

Table 1: Factors influencing the diffusion of high-tech products

* Factors proposed by Easingwood and Lunn (1992): firm s environment (regulation, macro trends), target group (consumer/industrial, niche/mass), company barriers (resources, specialisation), product characteristics (relative advantage, compatibility, complexity, triability and observability/communicability) and perceived risk of adoption (performance/financial, professional/social)

* Factors proposed by Wilkinson (1996): social (demographics, values, lifestyles), economic (macro; micro, company-specific), political (electoral, legislative, regulatory) or technological (direct, indirect enabling)

* Factors proposed by Cooper (2000): political, behavioral, economic, sociological and technological, to be analysed at three complementary levels: the firm, the business ecosystem and the infrastructure.

* Criteria selected by Noori and colleagues are organised in two broad categories relating to the 'micro' and 'macro operating environment'.
  - The main micro criteria are: other key players, regulation/legislation, technology (differentiating between the core technology and other complementary technologies), competition (who are the other firms and organisations with EV projects, and what are the characteristics of their proposed product: product features (especially regarding environment), customer voice (organised groups addressing the subject and their position).
  - The macro operating environment is analysed in terms of: social factors, economic factors, political factors (including present political situation, positions taken by different political parties, etc), technological factors.

There are, of course, different ways of using scenarios and evaluations of the 'external' environment. Cooper (2000) and Noori (1999) share the view that scenarios have to be made about the future world in order to identify uncertainties, that by taking account of the present situation and the firm's competitive advantages, it is possible to determine steps that should be taken to clarify these uncertainties and that such monitoring has to be repeated periodically because development paths are discontinuous and because it is important to build in additional moments of 'opportunity recognition'.

In short, the purpose of external evaluation is to help estimate the risk involved and to determine what action to take next. This reasoning prompts authors like Cooper to develop proxi-quantitative methods (in his case, using Bayesian networks) of systematic screening. This requires heavy investment, as is witnessed in the cases described both by Cooper and Noori. Such methods have another major limitation, namely, how are managers to prioritise amongst the multiple unknown issues to be addressed. In addition, this externally oriented approach encourages writers to concentrate more on the organisation's ability to adapt flexibly and to respond as an externally determined future unfolds than on internal resources and capabilities. This might be a realistic model in particular situations, but it contradicts the conclusions of Van de Ven and colleagues (1992), who highlight the 'chaotic nature' of the initial phases of a project, when learning is focused on identifying the universe of possible courses of action, when the relation between actions and outcomes is unclear, and where 'true ambiguity' prevails.

There are other reaches of 'unknowability'. As Noori and colleagues acknowledge, consumers are 'generally not aware of the needs revolutionary products will meet'. Furthermore, 'substantial customer learning is often a prerequisite for use'. Specific techniques have been developed to cope with these issues, such as information acceleration or lead-user analysis, methods which may be useful but which fail to address the problem of managing the process as a whole. In addition, the success of breakthrough products/services often depends upon the existence of an enabling infrastructure (e.g. 'the existence of regulations that permit and/or encourage the use of the product and the development of social values consistent with market acceptance'). This means that firms must develop an 'awareness ... to changes in the environment' and even take a 'more proactive approach' to 'control the evolution of their environment'. This leads Noori et. al. to conclude that project timing should be developed 'in accordance with the evolution of environmental factors' and not 'according to an absolute time schedule with a goal of reducing time to market as is customary'.

In response to problems of this kind, Cooper (2000) proposes a 'planning process' which provides 'a place to start, a direction for improvement and a way to update continually a dynamic planning document'. In this account, the place to start is an 'extensive situation analysis' that 'pays particular attention to environmental change that comes from political, behavioral, economic, sociological and technological sources' at three complementary levels, those of 'the firm, the business ecosystem and the infrastructure'. The objective is to 'help planners to stay divergent enough in their thinking (so) that the major potential threats and opportunities are more likely to be identified', and 'fundamental issues elicited'. This helps in building a 'critical-issues grid' which 'provides a framework that takes some of the randomness out of the process, or at least widens the scope for potential conclusions'.

Cooper considers that such an approach represents a partial answer to the challenges identified by Arthur (1988) or Van de Ven (cf above). Or at least, it does so provided 'the stakeholders and factors identified are woven into economic webs surrounding the new product'. Cooper suggests using Bayesian networks 'in which the arcs connecting nodes reflect the conditional probabilities of outcomes'. For Cooper, the value of using Bayesian networks is that it forces 'consistency and completedness' of storytelling. To build a complete Bayesian network 'involves a combination of knowledge engineering (i.e. a process of

translating existing expertise into conditional probabilities) and specification of focused research projects to develop estimates for the unknown arcs'. The latter helps identify directions for improvement. For Cooper this approach makes it possible to permanently adjust the 'economic web'. He writes that: 'at first numbers can be crude', only 'directional approximations of the underlying processes' can be mapped but concludes that the accuracy of networks (will) improve 'as the experience and expertise (of the planning team) grows' and 'as events unfold'.

Studies of breakthrough innovation all insist upon the need for dynamic monitoring. However the strategies put forward remain very much in line with recommendations that also apply to non breakthrough innovations. As a result, they do not address the central 'hierarchical' issue of how judgements are to be made, priorities determined and funds allocated in advance.

As we have seen, one key characteristic of breakthrough innovations is that the outcome of the innovation process can not be calculated. For the most part, methods of evaluation suppose that 'getting it right' is a matter of correctly anticipating events and responding accordingly. Such an interpretation places much weight on the skills of individuals blessed with intuition and a capacity for (more or less systematic) foresight. From a management point of view, it is risky to rely so much on the insights of just one or two individuals.

Is this the only way? Does the fact that breakthrough innovation processes can not be calculated prevent from managing them? As we will show in the following section the answer is no. Lessons from science and technology studies can help equip strategic managers and provide them with tools with which to handle and conduct breakthrough innovations.

We drew three major lessons from the sociology of science and technology:

First, the innovation process can be seen as a process by which a very unique and local phenomenon is transformed into a stable, predictable, calculable product — in our words, robust - something that a firm can manage and invest in according to conventional criteria (Callon 1998, Jolivet 1999)

Second, breakthrough innovation process cannot be calculated, but they can be described (Latour et al 1998). .Eliciting the learning steps through which managers seek to provide their innovation with stability, predictability and calculability helps determine a route for managing breakthrough innovations and for evaluating the quality of their management.

Third, innovative proposals embody visions/assumptions about the future world in which the innovation will be used (Akrich 1992 De Laat 1996). These scripts, or scenarios, made by the project manager, will be more or less widely shared by other people concerned about product diffusion and use (users, shareholders, stakeholders).

In the next section we show how we built on these insights and possibilities.

3 Learning from innovation studies

In this part of the paper we identify identify and elaborate on a number of themes explored within innovation studies and relevant to this discussion.

Articulating assumptions

Innovation studies highlight the simultaneous technical and social shaping of innovation. This means that in any research project, however scientific and technical its formulation may be, there is a simultaneous set of assumptions about the 'future working world', and about the prevailing 'norms' and 'rules' which characterise that world. Projects thus contain and embed

a 'script of the future' which it is important to 'de-script' (Akrich, 1992 and de Laat, 1996). To put it briefly, these assumptions concern the technological characteristics of the innovation, the way they are valued, the future organisation of the market (regulations and norms including the way that competition is organised between producers) and the relation with future customers (in particular how consumers are categorised, what competences they are expected to have and what form user-producer relations are expected to take).

In other words, actors and their projects de facto build 'endogenous scenarios' about a future world that will be receptive to their innovation and make it successful. These de facto scenarios revolve around a selection of factors that are believed to count, factors which in turn point to relevant transformations which must be realised or at least monitored. This idea is of practical significance. If project managers articulate their de facto scenarios (these are usually tacit and only rarely formalised), they will be in a position to identify the 'key changes' required (what sociologists of innovation have termed 'obligatory passage points'), they will have a position from which to start, and a sense of the route to follow.

Active exploration

One of the major results of the work piloted by Van de Ven is to have focused management research on process and not outcome, and to have introduced the notion of the innovation journey. Seen ex-post, the innovation journey consists of 'a sequence of events that create and transform a new idea into an implemented reality'. In real time this is 'an exploration into the unknown process by which novelty emerges'.

Looking at the literature, Van de Ven and his colleagues identify two dominant approaches to describing and analysing the process of exploration. One is to view this as a cyclical and deterministic pattern of learning by trial and error (where 'change is occurring through the positive or negative feedbacks between the actions undertaken and the outcomes experienced'). Another is to view innovation as a stochastic process of exogenous random events (where 'each innovative event represents an independent and equally likely draw from an underlying probability distribution of possible actions'). They consider that the second approach 'provides little intelligence for undertaking the innovation journey' and 'leads to ad-hoc explanations of the innovation process'. Their case studies showed that cyclical understandings (approach one) only came to the fore at the end of the process 'when actions and outcomes become tightly linked'. At the same time they showed that 'either the innovation units learned nothing during the first years of development efforts, or that they engaged into some other type of knowledge not included in the definition of learning'.

Following March,[1] they propose an 'expanded definition of learning': 'The definition of learning presumes that learners have some a priori knowledge about (1) alternative courses of action that can be taken, (2) outcome preferences or goals that are desired, and (3) the institutional rules, resources, and setting in which the task is undertaken'. An expanded definition of learning 'examines not only how action-outcome relationships develop, but also how prerequisite knowledge on alternative actions, outcomes and contexts emerges'. This prompts them to view the innovation journey in a new way.

> The parallel but separate chaotic branching that was found in action and outcome events during the initial period of innovation development creates a variety of experiences with alternative courses of action and a variety of enactments (or thought trials) of performance goals or possibilities. Building such repertoires of action experiences, outcome preferences, and contextual practices increases the likelihood

[1] 'Exploration (in organizational learning) includes behavior reflecting the search, discovery, experimentation and play of new courses of action, while exploitation includes the choice, refinement, implementation and execution of a particular course of action' (March, 1991).

> of making creative connections between means and ends when actions and outcomes are related ... By uncoupling actions and outcomes, a chaotic process facilitates the construction of repertoires of action experiences, outcome beliefs and contextual practices. These repertoires increase an organisation s capacity for creative learning. The coupling of actions and outcomes narrows the repertoires to those that satisfy the linear combination of feasible actions and desired outcomes. ... This narrowing process signals the transition from chaotic to orderly development.

Whether or not one agrees with the reference to chaos, this approach puts the capacity to manage the period of 'ambiguity', that is the period when traditional mechanisms of accumulation do *not* apply, at the core of the unfolding process. These authors suggest that *exploration* is at the heart of the initial phases of breakthrough projects. The result of such exploration is to learn whether or not there is a possible project and if so, which one it might be. It is only then that the 'narrowing process', usually involving sequences of 'trial and error', can take place and only then that traditional management tools apply

Trails of trials

One central feature of work on the dynamics of innovations concerns the process of enrolment. To establish the feasibility and to determine the potential of a want-to-be innovation, there is no option but to interest actors and persuade or make them share the objectives pursued: that is, to get them to accept both the vision of the future world and the path to be followed.

This introduces further questions, first about the capacity to mobilize new actors. Rip (....) has shown the importance of the 'promise-requirement circle' as a mechanism of continuous mobilisation. As described, the initial promise that attracts new partners to a project is consolidated through the trials made and the results achieved. Whatever their relation to the initial promise, the results of a trial help in closing one loop and in reassessing the relevance of the trajectory as initially defined. Latour (1987, 1993) suggests that what characterises the exploration phase is the inability to attract new actors considered necessary for the project's future whilst also keeping on board those already present. In any event, the process of desiging trials and learning from the results is a process in which the project is continually reconfigured, as are definitions of the relevant knowledge needed and the actors who must embody it. This changing actor configuration represents another dimension, or more accurately, another manifestation of the changing construction of Van de Ven s prerequisite knowledge and the 'progressive' specification of a repertoire of 'adequate' actions, outcomes and contexts for the want-to-be innovation. The progressive stabilisation of the assembly of actors, to the point that adding new actors no longer requires dis-interesting others already present, is itself an indication (and hence a means of monitoring) the 'narrowing process' mentioned by Van de Ven.

A second aspect concerns the stages through which an innovation goes. Looked at ex-post, it is clear, at least in radical/architectural innovations, that the final product will have gone through the well known states of basic knowledge, concept shaping, pilot, prototype, final design and industrial development. However, when looking at detailed histories of specific innovations, one result is also clear: this linear sequence of events is rarely encountered in practice. Most innovations studied by innovation analysts have gone through such states, but often more than once, and always in an 'ad-hoc' order.

It might help to replace traditional classifications of the state of a project with other typologies better able to characterise the changing status of a project. While the 'old' classification provides a still useful description of 'technical' states, there is a second 'societal' dimension relating to the 'space' in which this technical state exists. The 'spatial' aspect concerns the scope, reach, and the more or less collective nature of the trials or experiments made to

date. For example, pilot studies devised within one company laboratory do not have the same meaning (or reach) as those developed by a consortium including multiple companies, some interested users and a championing public authority. Looking at different breakthrough innovations in energy and in biotechnology, Rip and his colleagues Schot and Schaeffer (...) emphasize the importance of 'strategic niche management', that is the deliberate construction for a given period of time of an institutionally and socially protected space within which further elaboration can be undertaken. Similarly, looking at innovations in transport, Latour emphasises the role of collective experiments or socio-technical demonstrations the purpose of which is to test some of the heterogenous hypotheses made about the technical, social, political and economic configuration envisaged by the want-to-be innovation. This argues for complementing the terminology of technical 'states' (pilot, demonstration, etc.) with another one characterising 'spatial' extent of the 'trials' undertaken. Accordingly, project development could be described in terms of the trail of 'trials' through which hypothesised configurations of human and non human actors are progressively tested.

Assessing robustness

Trials serve to test the validity of hypotheses made by the innovation-in-waiting. However, one further problem is that of assessing the extent to which uncertainty has in fact been clarified. The next question is this: how can one know that actors *are*, in fact, enrolled and that uncertainties are indeed clarified? There are two aspects to this. The first lies in what the sociology of science calls the 'robustness' of propositions. Propositions are said to be robust when the assumptions on which they depend are no longer challenged. To grasp the extent of 'robustness' - that is to determine the range of situations across which assumptions are no longer challenged - it is important to characterize the fora or arenas in which these propositions have been debated, accepted and come to be taken for granted ('naturalised' following Latour). The second has to do with relevance: are the actors involved appropriate and adequate 'representatives'? What is at stake here is not some form of elective representation, but rather a question about the extent to which those involved provide access to relevant dimensions and features given the project's targets and ambitions. Von Hippel introduced the notion of 'lead users' to define those participating in the definition of needs, in shaping the functionalities of products, in understanding the required user knowledge base, etc. More widely, authors have since coined the term 'spokesperson' to describe those who are believed (or used) to speak on behalf of others.

The practical challenge is therefore one of assessing the spokespersons' representativeness, or to use Courtney's terms, it is a matter of getting the measure of their market shaping capability. Courtney speaks of credibility, a notion that has been used in science studies when considering the conditions under which researchers and their proposals gain recognition. In exploring this issue, Rip and Callon (Rip 1986, Callon and Rip, 1992), have underlined the role of controversies and of the 'hybrid forums' in which credibility is built. To paraphrase the insights that Rip derives from his analysis of cigarette smoking and cancer in his seminal 1986 article on controversies, 'A new knowledge has no impact by itself, but only when taken up by forceful actors'. Given uncertainty, it is not only the cognitive element that counts. When a controversy is resolved, 'a certain view of the issue has become dominant and widely available'. Opponents (like the US Tobacco institute in his example) have, for instance, stopped presenting a dissenting view now that they are 'running up against arguments, evidence, social alignments, interests, and cultural values, many of them interrelated and therefore lending support to the dominant view'.

In such debates, 'not truth, but impact is what counts', 'not substance, but sociocognitive strategies and their outcomes should be the focus' - and in our case, they should also be the focus of the trials to which innovations-in-the-making are subject. Put another way, the successful conclusion of a trial has to do with establishing and enhancing the robustness of the outcome. 'Robust is whatever holds on its own'. The degree of robustness is linked not

just to the 'spatial' dimension (discussed above) but also to the hybridity of the forum in which the controversy and its related debates took place. In other words it is also relevant to take account of the types of actors involved, the types of arguments exchanged, and the types of modalities involved in voicing and reaching closure.

By implication, the new configurations of scientific, social, economic, political and cultural linkages on which breakthrough innovations depend have to be visible and have to be discussed and debated if they are to gain recognition and support. Developing this point, the degree of robustness required (in terms of scope and hybridity) will determine the type of market entry and the properties of the initial niche that the want-to-be breakthrough innovation might reasonably aim for, as a first foot-hold.

To reiterate, the results of a trials can be described in conventional terms (for example: 'we now have a prototype that works under such and such conditions') and with reference to the extent to which actors judged critical to the success of the want-to-be innovation are interested and enrolled. In practice this is likely to involve, 'a coordinated set of heterogeneous actors — laboratories, technical research centers, financial organizations, users ... and public authorities — which participate collectively in the development and diffusion of innovations, and which organize, via numerous interactions, the relationships between research and the market place' (Callon).

Callon (1991), Callon et al. (1992), and Laredo and Mustar (1996) refer to this set as a 'techno-economic network' (TEN). This terminology is used for two reasons. First to make the point that the network includes technical devices as well as social actors. Second, to underline the various modes of coordination involved and the role of intermediaries in sustaining the network as a whole. The business of following an innovation-in-the-making (as it develops through a series of trials) is therefore an exercise in following three dimensions of network development: namely, the actors that make it up, the intermediaries that circulate between them, and the network's capacity to position itself as a collective actor vis- -vis the external world.

To summarise, authors like de Laat (1996) and Akrich (1992) confirm the importance of 'scenarios' as visions of the future working world, but challenge the fact that scenarios have to do with external developments; instead, scenarios are first and foremost inscribed in projects which consequently presume a 'script' of the future, a script which it is important to 'de-script' in order to assess the scope and reach of the transformations/changes required. Developing this idea, other writers have identified the need to complement traditional but static and technology bound classifications of 'states' (such as pilot, prototype, etc.) with a means of recording and tracking the 'trials' to which projects are subject and through which they advance. This notion of testing and trialing makes it possible to incorporate and acknowledge features identified by other analysts, for example, Noori's observations about the development of user knowledge and the emergence of appropriate (and necessary) social and market infrastructures. This points to a further need: that is to assess the relative strength or durability of arrangements and networks built around innovations-in-the-making. How robust are they, in what fora have relevant controversies arisen, how and where have they been tested, and how fragile or rugged is the outcome?

Critically, this tracking, trialing, network building, testing and de-scripting is important not as a matter of 'record' but as an active part of the process: reflection, learning and repositioining being the 'engines' of effective innovation. Evaluation is, in other words, part of developing the vision of the future market, identifying the uncertainties faced, selecting issues in urgent need of clarification and defining the next round of actions through which to further explore the possibilities. Furthermore, all this is based upon actions previously undertaken, the results of which in turn help sharpen the vision of the future market and reduce the uncertainties faced.

4 Putting innovation studies to work

Though the observations made above are abstracted from academic and typically retrospective studies of innovation they contain hints and clues as to possible courses of action. One aim of SOCROBUST, an EU funded feasibility study, was to develop and test an approach to the management of breakthrough innovation explicitly grounded in - and derived from - these insights. In this section we say something about how we tackled this project and briefly outline the 'method' we developed. The purpose is to simply give a flavour of what was involved, not to describe the process in any detail (see the SOCROBUST final report for further details).

From the start, we imagined the SOCROBUST method being used by project managers responsible for risky, breakthrough innovations and facing the problem of deciding what to do next to enhance the chances of success (that is, to increase their project's societal robustness) given the uncertainties involved. In essence, our strategy was to review literature from management and innovation studies, identify relevant concepts, design a method for putting these into practice and then test this 'prototype' on eight current projects.

Although literatures of the kind referred to above work with attractive and potentially relevant concepts, many such ideas are born of theoretical consideration alone and have never been tested in real life. Partly because of this it was no easy matter to select concepts and turn them into serviceable 'tools' that might be applied in practice. This is one lesson on which we comment later.

A second challenge was to devise a coherent framework or sequence of steps (each involving the use of different but interconnected 'tools') that could be followed and repeated at different points in the career of a breakthrough innovation. In constructing the steps of the SOCROBUST method we mirrored the flow of argument developed above. As a result, the first move (step 1) is to articulate the future world inscribed in the project. The next (step 2) is to identify the key changes required by comparing the characteristics of the future world (as inscribed in the project) with the characteristics of project's present (techno-economic) network. It is then possible (step 3) to assess the robustness of assumptions already 'contained' within the project (associated with anticipated key changes), for example by identifying competing views of the world and by thinking about how key changes might actually come about. The final move (step 4) is to identify the project's margins for manoeuvre: what can in fact be done, in the present circumstances, to make these changes happen?

Step 1: Description

The SOCROBUST method begins by revealing the image (or images) of the 'future world' already embedded in the project and wrapped up in implicit assumptions about future users, values, rules and infrastructures. At any moment, a project manager is in a position to provide a narrative account of his/her project. In telling the 'story' of their project's career, in detailing the ambitions and assumptions it embodies, and in describing turning points and moments of 'irreversibility' that have already passed, project managers are obliged to recall the trajectory to date and reflect on what this means for the future.

The project narrative is the starting point for a process of systematic re-description. One such move involves mapping the actors (currently) involved, showing where they are positioned, how they relate to each other and which intermediaries bind them together. This exercise establishes the richness, heterogeneity and durability of the project's present network. It also reveals the existence of other actors (for example, competitors with 'similar'

or different approaches to market shaping) and helps identify 'blanks' or areas so weakly or so generically developed that they are not as yet involved in the project at all.

Step 2: Strategic changes

The next step identifies the key changes that will be required if the gap between the present state of affairs and the desired future world is to be closed. What is needed before the anticipated future becomes a working reality? In tackling this question, project managers have to visualise the network as it will be when the project has achieved its goals. This future oriented exercise allows project managers to identify critical actors who have yet to be enrolled and aligned. It also generates a project-specific point of reference against which to assess the extent of necessary or assumed changes in the market infrastructure, in the user knowledge base and in producer-user relationships. The trick here is to compare the present state of the network and the hoped for future working world, and thereby isolate the key changes involved. It is then possible to think about how each of these key changes might be addressed. Can they be handled within the present network or will it be necessary to involve new actors? What are the project manager's views of these options: can the project be pro-active? Can it recruit adequate spokepersons and thus shape the issue (or at least participate in its shaping) or can it do no more than monitor events that are effectively 'made' elsewhere? If so, the challenge is one of remaining flexible and adaptable and of watching for early warning signs of negative developments.

Step 3: Assessment

It is not enough to imagine a future to make it come true. Major threats include those posed by alternative images and visions of the future backed by strong, diversified, or powerful networks of actors and by the alternative 'scripts' incorporated in existing artefacts. In other words, the convergence (or difference) between the project manager's vision of the future and those circulating in the wider world or espoused by other actors interested in similar questions, requires clarification. In short, are the project's core assumptions robust?

What can be said about the probability that the key changes (specified above) will come about? At this point the SOCROBUST method involves making a quite specific external check (that is a check on the world in which the project is developing) designed to determine how well grounded the project's key assumptions really are. The results of this checking process are represented in what we refer to as a 'positioning table'. This shows how the project stands with respect to alternative methods, strategies and technologies; it identifies potential allies and opponents and it shows how other actors are organised within the field. The result is a snapshot of how the 'key changes' required by the project are positioned with reference to:

- Developments in the technological landscape (for breakthrough innovations these are often associated with new paradigms or new dominant designs, in other words, to the development of new knowledge about what the technology can do and how to do it),
- Developments in user-producer relationships (this includes all aspects of customer preferences, market segmentation, the new knowledge customers will require to use the proposed products and/or to be in a position to value their new qualities.)
- Developments in the legal, administrative and regulatory environment (this includes all well-known issues about norms and standards, but also ethical issues, issues about the environment, and about quality and consumer safety).

The result is a focused test of the main assumptions underlying the project's vision of the future world. This serves to determine the main areas of uncertainty and the main alternatives? It shows how these are expressed and debated and where and in what contexts (or fora) controversies arise.

Step 4: Lines of action

Having 'positioned' the project in this way it is finally possible to address the strategic question of what can be done next either to adapt the innovation to the societal world in which it must exist or to adapt the social world to suit the innovation. The fourth step helps managers recognise what is within and beyond their scope for action with respect to each of the key changes required. In some cases the ensuing recommendations are active: to build, test, demonstrate etc. Yet they may also include taking precautionary measures especially regarding features over which project managers have no direct influence. In these cases, the form of 'watching' might be traditional, that is passive. But it might also be much more pro-active, for example, continually monitoring specific developments, reflecting upon routes not taken within the project (and being alert to the potential weaknesses that may arise if competitors take these routes), or refocusing the project's ambitions (depending on its flexibility).

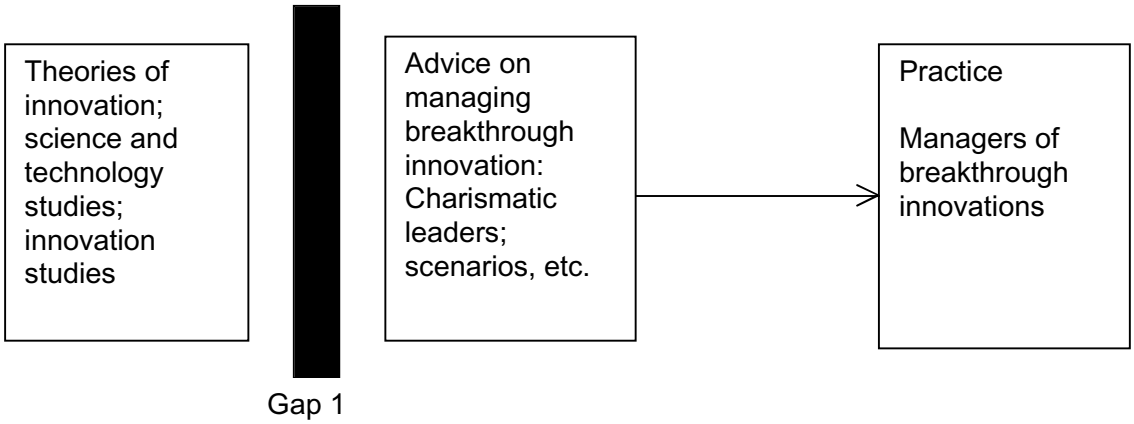
As this brief review makes clear, the result is a carefully constructed method that embodies a particular understanding of what breakthrough innovations involve. We have tried the SOCROBUST method out on eight contrasting projects and in all cases found that it produced what managers took to be useful and valuable insights and suggestions for action. However, and this is a critical point, our involvement in these cases was limited. In effect we offered a SOCROBUST review as a form of one-off, experimental, consultancy. The managers of the eight projects with which we worked were at liberty to reject our conclusions and had little to lose by taking part.

We have since sought (but failed) to interest a major multinational company in adopting the method. In the next section we reflect on some of the problems encountered in developing and in trying to 'embed' the SOCROBUST methodology.

5 Lessons and reflections

To go back to the beginning, this paper began with a critique of current advice on managing breakthrough innovations. Put simply, we argued that such guidance has for the most part failed to take account of relevant conclusions and insights developed within science and technology studies or derived from empirical analysis of breakthrough innovation. In other words, we identified a (first) gap between theory and practice. Figure 1 provides a crude illustration of this divide.

Figure 1: Gap between innovation studies, management advice and practice

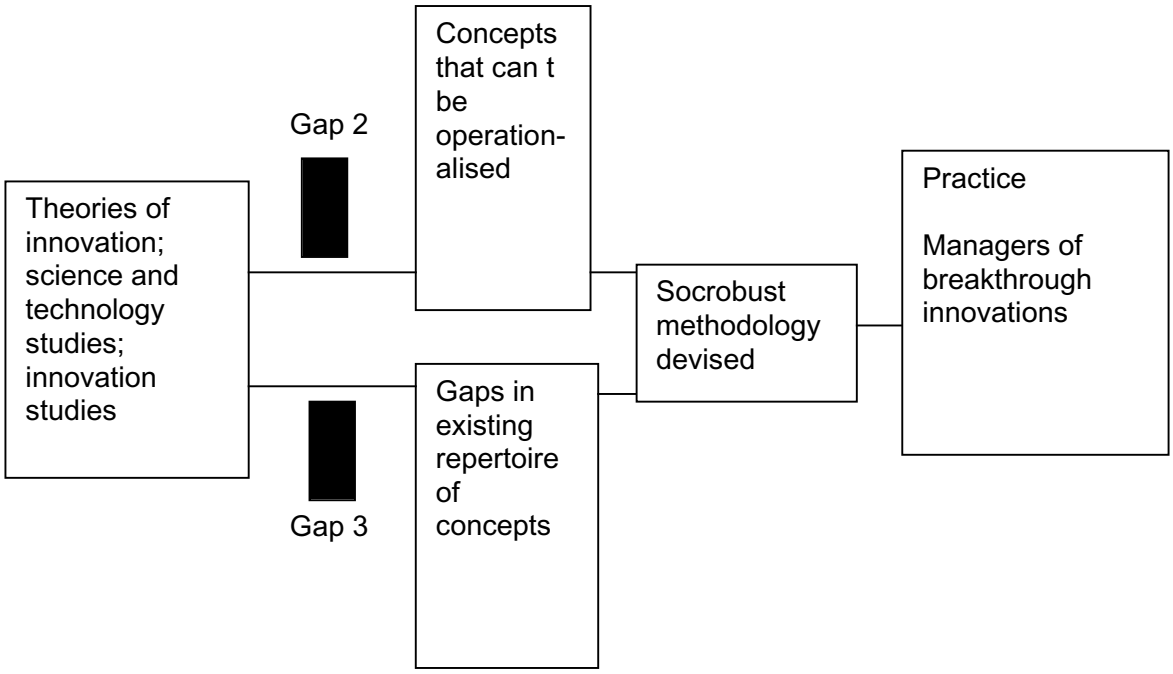


To give a brief example, organisational procedures are routinely designed to harness and channel individual insight:, assuming that this is indeed the talent that is required to engender breakthrough innovation (Chen and Van de Ven 1996). Alternative approaches to managing the incalculable (such as that outlined above) are founded on a different understanding of what is involved. More than that, they are founded on an understanding that does not rely on (and therefore does not need to reward) elusive and exclusive qualities like those of intuition and charisma. In political terms, the insights of science studies threaten to undermine or at least challenge established hierarchies of influence and status, and associated organisational structures, hence the solidity of the thick black divide illustrated in figure 1.

In trying to respond by mobilising concepts from innovation studies and turning them into useful tools and techniques we encountered a second gap. It was often not possible to operationalise persuasive and theoretically attractive ideas developed within the realm of academic enquiry and debate. Convinced that the underlying theoretical models of innovation and change *were* relevant for management and practice, we struggled to make them so. Not surprisingly, researchers concentrate on retrospective cases. Avenues of theoretical development (inadvertently) reflect this preoccupation. By contrast, our task was to develop ways of putting such ideas into the present tense and of using them to inform and guide future action.

The SOCROBUST method represents our 'solution' to this problem. In devising it we discovered further gaps and omissions in the available repertoire of intellectual resources. It wasn't simply a matter of turning concepts into tools but of also moving into uncharted territory, learning, re-positioning and inventing new ideas along the way. Figure 2 identifies these two types of gap and suggests that we found ways of bridging them.

Figure 2. Gaps between theoretical constructs and operationalisable concepts.



We were, for example, keen to make use of retrospective studies that had systematically recorded the course of technological trajectories and that had followed their transition from 'niches' on to the wider world, or that had tracked their progress with the use of 'stability indicators'. Although the theories behind these concepts and measures remain important, their retrospective orientation (and the amount of data required to operationalise such notions) prevented their ready incorporation into a workable tool. We also confronted the need to develop new ideas, for instance, in order to define and describe an organisation's capacity for manoeuvre having established the present positioning of their innovation-in-the-making. In concentrating on the 'needs' of project managers we 'saw' the established repertoire of academic concepts in a new light.

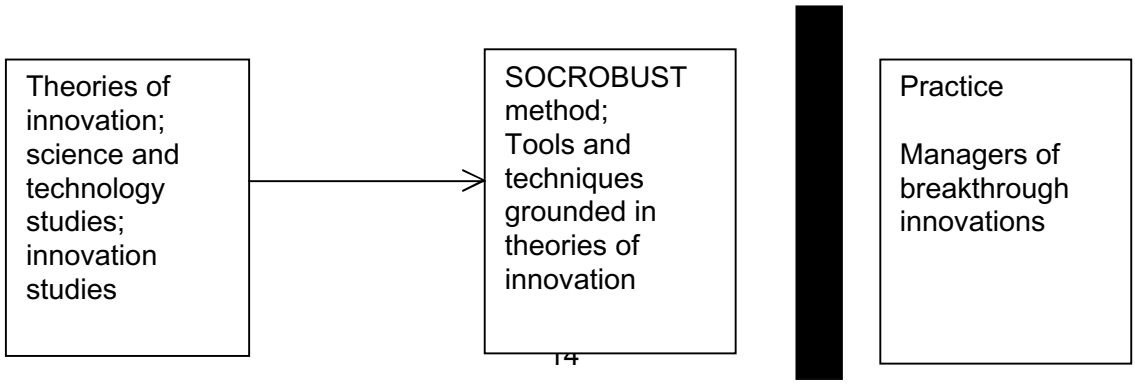
For all its limitations, the resulting method is theoretically coherent: each step embodies and builds upon a clear sequence of argument and conceptual reasoning. In this respect - and after much effort - it really does exploit the fruits of recent research.

And it worked well as a framework with which to provide consultancy and advice. However, we have recently discovered a fourth kind of 'gap', this time between the orientation to management supposed by SOCROBUST and that which (sometimes) exists in practice. Because we were committed to the task of 'improving' the theoretical consistency and coherence of management methods for breakthrough innovations we overlooked the political and symbolic dimensions of project management.

As we have already noticed, conventional forms of advice place considerable weight on project managers' capacity for visionary insight and their ability to attract resources and attention. Such observations lend weight to a model in which 'failure' is a problem and in which making radical revisions to project plans is a sign of weakness or trouble. By implication it is possible to get 'it right first time' - even for breakthrough innovations. Indeed the rarity of such success only enhances the perception of the flair required. By contrast, the SOCROBUST method is built on a different understanding of what is involved *and* therefore on a different concept of the project managers' role in the process and within the organisation. This understanding is one in which learning, experimentation, trialing, testing and revision are central and in which reflexive understanding and continual monitoring of the project's 'positioning' involves revisiting and sometimes questioning the core assumptions around which the project is built. Stratgically courting controversy is part of the game, not something to be avoided, and so we could go on.

The fourth 'gap' therefore has to do with prevailing understandings not simply of the theory of innovation but of the corresponding status and role of the project manager. It is, for example, likely that an organisation that wanted to adopt a SOCROBUST style approach would have to make quite extensive changes to the way that project management is viewed and valued. Having carefully carved a channel between innovation theory and practice (through developing the SOCROBUST method) we run up against the everyday realities of organisational politics. Figure 3 illustrates this final 'gap'.

Figure 3. Gap between theories of innovation and the politics of project management



Our experience of trying to persuade a large company to adopt or at least experiment with SOCROBUST provides a telling indication of the kind of divide involved. Intellectually, the managers with whom we spoke were convinced: they recognised the problem that the method was designed to address, they knew that their 'normal' procedures did not cope well with cases of breakthrough innovation and they were attracted by the logic of the SOCROBUST method. But The challenge of unpicking deeply embedded ways of working and long established procedures of project was simply overwhelming. Their conclusion was unanimous: it simply would not work 'here'.

There are, of course, other possible interpretations: that the SOCROBUST method is not as convincing and credible as we have made out; that we were just unlucky; that we tried to promote the method to an unusually staid and traditional organisation, and so on.

Nonetheless, this account raises a number of generically revealing questions about the relation between theory and practice. As others have observed, the development of theory routinely involves abstraction from practice. This can present problems when it comes to 'reversing' the process and putting abstract concepts to work for real (as we discovered and as indicated by gaps 2 and 3). For these reasons, it is perhaps no wonder that practical advice is often divorced from contemporary theory (gap 1). This goes some way towards explaining the first three of the 'gaps' described above. The fourth is another story. This 'gap' serves as a compelling reminder of the rather obvious sociological point that project management is not just theory, it is also social and symbolic work and is as such embedded and embodied in existing organisational contexts. These situational and structural features may be such that certain theoretical approaches - in this case those grounded in innovation studies - are unlikely to be appropriated by practitioners, even when there are relevant and appropriate tools to hand and even when everyone (rhetorically) agrees that their application promises to be of real benefit. To put the point more generally, what would organisations and project managers have to be like in order to really exploit the insights of innovation studies?

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