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Abstract

Science, Technology and Innovation Studies show that intensified user producer interaction (UPI) increases chances for successful innovations, especially in the case of emerging technology. It is not always clear, however, what type of interaction is necessary in a particular context. This paper proposes a conceptualization of contexts in terms of three dimensions – the phase of technology development, the flexibility of the technology, and the heterogeneity of user populations – resulting in a classification scheme with eight different contextual situations. The paper identifies and classifies types of interaction, like demand articulation, interactive learning, learning by using and domestication. It appears that each contextual situation demands a different set of UPI types. To illustrate the potential value of the classification scheme, four examples of innovations with varying technological and user characteristics are explored: the refrigerator, clinical anaesthesia, video cassette recording, and the bicycle. For each example the relevant UPI types are discussed and it is shown how these types highlight certain activities and interactions during key events of innovation processes. Finally, some directions for further research are suggested alongside a number of comments on the utility of the classification.

Keywords: Innovation, users, interaction, learning, typology of UPI

Introduction

Innovation studies show that intensified user producer interaction increases chances for successful innovations. Through interaction users and producers are better able to overcome uncertainty about customers' needs and preferences and about the characteristics of technology; the needs of users can be identified and their role in innovation processes strengthened (Clark, 1985). Producers are interested in societal acceptance of their products, in access to users' knowledge and in mobilizing the creative potential of users (Smits, 2002; Oudshoorn & Pinch, 2003). Users are increasingly recognized as important sources and co-developers of innovations. Various studies show that users often develop new functions for technologies, solve unforeseen problems and propose or even develop innovative solutions (Von Hippel, 1976; Lundvall, 1988; Coombs et al., 2001; Luthje et al., 2005; Rohracher, 2005). A growing body of literature in the field of Science, Technology and Innovation Studies addresses the variety of ways in which users can be involved and the question how interaction between users and producers can contribute to the quality of innovation processes. We think there is now opportunity and need to wrap together the results of these studies and try to bring some order in the variety of what we call 'types of user producer interaction', that is: the characteristics of how the process of user producer interaction is organized and develops. In this study we classify types of interaction based on a particular structuring of contexts.

Starting point in this study is that user producer interaction (UPI) is an umbrella concept covering various types of interaction, such as demand articulation (Boon et al., 2008), interactive learning (Lundvall, 1988), learning by using (Rosenberg, 1982) and domestication (Silverstone & Hirsch, 1992). Types of interaction are interactive learning processes between users and/or producers leading to or aiming at the reduction of uncertainty about the relation between product and demand characteristics. More specifically, these are interactions that lead to outcomes such as articulated demands, improved modes of interaction, lessons about prolonged use and domesticated technologies. It is via these specific objectives that UPI can contribute to more general, meso-level objectives of user producer interaction, such as enhanced competitive strength of enterprises, improved acceptance and societal embedding of new technologies, improved learning capacity of social networks, or enhanced democracy (Smits & den Hertog, 2007). In this study, however, we stick to the specific processes and objectives when we identify and classify types of UPI.

A second important aspect is the setting, or organization, of UPI. There should be channels for communication and, especially in the case of tacit knowledge, a common language via which users and producers understand each other (Lundvall, 1988). Examples of settings are forums, user panels, usability trials, advertisements and after sales services. How UPI should be organized depends among other conditions on the specific objectives of UPI and on the characteristics of the context.

Much is known about the objectives and organization of UPI from the literature on science, technology and innovation. Case studies from several empirical domains analyze aspects of different types of user involvement and user producer interaction. But one problem of these case studies is that it is not always clear to what extent the results also apply to other cases. There are hardly studies that aim to synthesize the results of this field work. Existing overviews, e.g. those of Oudshoorn and Pinch (2003; 2008), depart from theoretical traditions and discuss the origins and relative differences of UPI types along theoretical lines, but in doing so underemphasize the (impact of) practical and instrumental aspects of UPI. Our research focuses on the contexts of application of UPI in order to serve those who actually seek to improve user producer interaction in practice.

While the ultimate purpose at the horizon of this research is to construct a 'toolbox' for determining which types of UPI are appropriate in what empirical circumstances and how this should be organized, the current paper reports about the groundwork performed for this goal: the contextualization of types of UPI. A detailed discussion about the organization of effective UPI is beyond the scope of this paper, though we do include references to studies, which discuss that aspect.

In the next section we propose a scheme to classify different types of UPI based on distinctions on three dimensions that we came across while studying the literature: i) the flexibility of the technology, ii) the heterogeneity of user populations, and iii) the phase of technology development. After elaborating these distinctions we discuss how we can classify the various types of UPI that are brought forward in the literature. Because we make use of many quite abstract theoretical notions we give four empirical examples to illustrate the value of our classification.

A classification of UPI

The basic premise of this research is that different contexts demand different types of UPI. It is already acknowledged that the nature of innovative activity changes along different phases of technology development (Collingridge, 1980; Utterback, 1994) with important consequences for the types of UPI that should be employed in these different phases (Rip & Schot, 2002; Stewart & Williams, 2005). In addition, we argue that it is useful to differentiate on two more dimensions: on the flexibility of the technology and on the heterogeneity of user populations. A short detour to another attempt to classify UPI types may clarify why these three dimensions are relevant.

In an inspiring article about user involvement in ICT innovation, Stewart and Williams (2005) distinguish between two perspectives – a design-centred perspective and a social learning perspective – and show how types of UPI belong to either one of them. The 'design-centred' perspective has its roots in early technology studies, which emphasized how values, interests, biases and priorities of designers become embedded in the material content of technologies. Such values are reproduced, or at least favoured, once these artefacts are put in use. Improved user producer interaction from this perspective would entail techniques to include users in early phases of technology development so that design decisions are much more likely to reflect values and desires of users. Human centred design, constructive technology assessment and participatory decision-making can contribute to this aim.

In contrast thereto Stewart and Williams put another perspective in which the innovative role of users is played in the context of use. This 'social learning' perspective starts from the assumption that technologies are essentially ‘unfinished’ when they enter the user environment. Technologies only work if they are well embedded into an often already existing context of use, comprising not only machines and systems, but also routines and culture. This means on the one hand that users need to adjust to the new technology and get familiar with its affordances and limitations. On the other hand, social learning often also leads to technological adjustments. If the use of technology reveals certain shortcomings of the original design, which designers overlooked due to their limited knowledge of the local context, then users can be important sources for improvement. In this perspective users are important innovators even when they have been virtually absent in decision-making in the context of design.

The distinction between the design-centred and the social learning perspective and the claims that Stewart and Williams base upon it are very strong. They state, for example, that the design-centred perspective is flawed, because it is impossible to anticipate the requirements of users in advance given the complexity, diversity, uniqueness and thus specificity of user requirements and contexts. No wonder, they argue, that human centred design approaches have “failed to generate distinctively different models of artefacts from those emerging from conventional design settings” (p.199). Along these lines, Stewart and Williams reject the design-centred perspective as the ‘design fallacy’ of (early) technology studies.

We believe, however, that Stewart and Williams can make such strong claims because their framework is polemical. The social learning perspective is appealing when thinking of cases of flexible technology, like ICTs. In those cases there is considerable freedom for users to configure technologies to their personal needs and wishes. By the same token, the social learning perspective is appealing when the user population is very heterogeneous and it is indeed impossible to anticipate user requirements in a comprehensible way. In those circumstances, innovation, adaptation and learning in the context of use would indeed lead to better technology. But what if technologies are not flexible? Nuclear reactors or vaccines cannot easily be configured to individual needs. And what if demands are not heterogeneous, but relatively homogeneous and quite well understood? Then a design centred perspective may still offer an appropriate understanding of design strategy.

For our purposes – to classify user producer interaction relative to the circumstances of a case – we need a more distinctive classification. One reason is that we do not want to limit the applicability of the framework to flexible technology in general and ICT specifically. Therefore we develop a classification based on distinctions on three dimensions that seem to be folded into one another in Stewart and Williams’ framework: the flexibility of technology, the heterogeneity of the users, and the phase of technology development.

Regarding the *flexibility of the technology* we draw on the conception of technology as a set of affordances and limitations that prescribes or suggests how an artefact should or could be used (Norman, 1988; Hutchby, 2001; Latour, 2002; Arnold & Mettau, 2006). Affordances and limitations do not determine user behaviour and capacities, but one can discern degrees of coercion (Latour, 1992; Oudshoorn & Pinch, 2003). Moreover, these affordances and limitations usually are not immediately clear; they must be discovered and learned when the technology is fit into existing networks and life worlds (Silverstone & Hirsch, 1992; Oudshoorn & Pinch, 2003) and such learning processes may give rise to technological adjustments (Rosenberg, 1982) or induce further technological innovation (Fleck, 1988; Von Hippel, 2005).

The rigidity (versus flexibility) of the technology is defined by the strength of the design logic, that is: the degree to which affordances and limitations are determined by the interrelatedness of components that make up a technological artefact. This degree determines the space for acting and learning and hence the relative importance of different types of user producer interaction. For example, very flexible technologies have weak design logics and are relatively easily adjusted to specific user requirements. Learning will be largely oriented at the mobilization of local expertise. Rigid technologies, in contrast, have a strong design logic specifying particular affordances and limitations. They demand a receptive environment and learning will largely be oriented at the possibilities for market creation, the mobilization of societal support and institutional change.

Flexible technologies may be offered as integrated systems or as loosely coupled configurations (Fleck, 1993; Fleck, 1994; Franke & Von Hippel, 2003). Loosely coupled configurations consist of mutually interacting components, both technical and non-technical, which may be deployed in a variety of ways to offer variable affordances and meet diverse user requirements. The main difference with integrated systems is that their affordances and limitations are shaped during the implementation process instead of prior to it.

Rigid technologies do not have the possibility of customized configuration at all. Rigid technologies are integrated systems by nature: they just do not work if one component of the system is changed without changing others (e.g. refrigerators, see below). Their affordances and limitations fundamentally depend on the interrelatedness of components, or on one specific and irremovable component in the system. Many drugs are examples of such rigid technology.

Turning to the *heterogeneity of the user population* we note that there are several sources of heterogeneity: user contexts are often unique as a consequence of contingent historical developments (e.g. existing technology, routines and institutions) (Fleck, 1994; Garrety & Badham, 2004); there may be different kinds of users of the same technology that have different needs and concerns (e.g. medical professional, nurses, patients, hospital administrators in case of medical technologies) (Oudshoorn & Pinch, 2003); and these users may have very different capabilities and knowledge bases (depending on e.g. education, skills, experience) (Akrich, 1995).

Our definition of user heterogeneity is derived from the Social Construction of Technology (SCOT) approach (Pinch & Bijker, 1987; Bijker, 1995; Kline & Pinch, 1996). In this approach a user group is distinguished from other social groups, such as engineers, advertisers and other users groups. Each of these so-called ‘relevant social groups’ shares a particular meaning of an artefact. With regard to the early development of the bicycle, for example, Pinch and Bijker (1987) distinguish the relevant user group of young men from the group of women and elderly because each group associated a different meaning with the bicycle (‘macho machine’ versus ‘unsafe machine’). We define user heterogeneity then as the existence or emergence of multiple relevant user groups. User groups are relevant when they are actively involved in disputes and interactions, for instance because they have a problem for which one variant of the technology might offer a better solution than another. Heterogeneous users thus put various, and sometimes conflicting, requirements to a certain technology.

The heterogeneity of users is an important dimension in our classification scheme. The more heterogeneous users are, the more complicated it is to align technological opportunities to user demand. Note, however, that opportunities for alignment also depend on the flexibility of the technology. In case of flexible technology, alignment will be sought in product differentiation (Franke & Von Hippel, 2003) and in case of rigid technology, in closure of controversy (Bijker, 1995).

The heterogeneity of users manifests itself during learning processes and user producer interaction, especially in early phases of development. For example, the construction of scenario’s, demonstrations and the articulation of demands and needs reveal the extent to which users attach similar meanings to emerging technologies and to which demands diverge or converge (Boon, 2008). However, user groups generally have coherence beyond the fact that their members share a certain meaning of an artefact: members share other properties as well, such as the meaning of related artefacts (predecessors, complementary products). To capture this coherence, Bijker (1995) has introduced the notion of a technological frame. Meaning attribution, and hence social group identification, takes place with reference to these more widely relevant and historically patterned technological frames. In other words, user heterogeneity manifests itself during processes of learning and interaction. But user heterogeneity may already exist prior to these processes in the form of different technological frames.

The definition of the *phase of technology development* is based on the conception of the dynamics of technology as an ‘innovation journey in context’ (Rip & Schot, 2002). The innovation journey is a certain path that technology developers follow. This path is not given in advance, but created by going along it in interaction with scientific, regulatory and market actors. Rip and Schot (2002) distinguish between three phases based on typical activities that take place in these phases. In the first phase, actors are building-up a more or less protected space (niche) via typical activities like identification of technological opportunities, mobilization of resources and articulation of functionality. In the next phase, the technology enters the wider world. This phase is characterized by activities like constructing and testing prototypes, identification of lead users, and market introduction of the technology. Rip and Schot also distinguish a third phase, sector level changes, which centres on activities like standardization, exploiting economies of scale and scope, infrastructural development, and process innovation. For practical reasons, we consider this phase as an extension of the wider world.

The distinction of different phases of development is inevitable for the classification of different types of user producer interaction, because user producer interactions are a subset of the cluster of activities that make up a particular phase. These interactions can then be studied in relation with typical activities in a protected space or the wider world.

A final comment to this dimension concerns the ontological status of the phases. The metaphor of an innovation journey emphasizes the idea that a technology travels from one place to another in a certain time sequence. In early phases, technology is kept in a protected space, while it leaves this space to enter the wider world in a later phase. However, activities in the respective phases may also take place in parallel and mutually inform each other (which Rip and Schot (2002) refer to as ‘feedback and feed-forward loops’). For example, while actors interact about lessons learned from prolonged usage in the wider world, new protected spaces may emerge around such interactions in which the possible application of innovative components or materials is explored. For this reason, we prefer the conception of the protected space and the wider world as different clusters of activities and interactions, which do not necessarily presuppose a time sequence.

We have distinguished and discussed three dimensions for the classification of types of user producer interaction. The phase refers to two distinct clusters of activities surrounding a particular technology. The flexibility of technology and the heterogeneity of users are two dimensions which define four particular technology-user constellation in which UPI types can be classified:

1. *Commodities*
    - Rigid technology: supplied without qualitative differentiation across a market segment, strong design logic
    - Homogeneous users: relatively uniform user contexts and well delineated market segments
2. *Ambiguous technologies*
    - Rigid technology: limited possibilities for adaptation, strong design logic
    - Heterogeneous users: specific requirements, conflicting interests in technology
3. *Integrated systems*
    - Flexible technology: configuration with emerging generic identity which governs how components are integrated
    - Homogeneous users: relatively uniform user contexts and well delineated market segments
4. *Configurational technologies*
    - Flexible technology: adaptable configuration composed of loosely coupled and changeable components
    - Heterogeneous users: unique user context, specific needs and requirements

At any given moment in time, a technology in its context can be typified in terms of one of these four constellations. That is not to say that shifts between these constellations cannot occur. Configurational technologies, for example, may evolve into more integrated systems when configurational activity becomes path-dependent, user requirements converge and system standards emerge. This may be the result of convergence on the dimension of user heterogeneity. Often, the number of social groups, their frames and the variety of models of an artefact decreases over time, when social groups achieve consensus about the dominant meaning of an artefact (‘closure’).

But this shift towards systematization and generic identity of a technology certainly does not need to happen. With examples from robotics, production systems and IT applications, Fleck (1993) argues that in many situations local contingencies continue to resist standardization and systematization. Some technologies may even evolve from systemic into configurational technology over time. New user groups emerge and add another frame to the same technology. This may have strong implications for technological design, for example when enthusiast user communities acquire technical skills and learn how to deconstruct generic systems to reconfigure them into technologies that serve their own purposes. In this way, users transformed the bicycle into a mountain bikes for sportive adventure in the 1970s (see below). Other examples are the transformation of the T-Ford into a stationary power source in rural America (Kline & Pinch, 1996) and the reorientation of genetic technology application from hospital services towards pharmaceutical drug development (Martin, 2001). In these examples, the emergence of new users resulted in differently configured technologies. In other examples, new user groups may also be formed around resistance to a given technology (e.g. nuclear power plants or wind energy parks) or around new applications of essentially unchanged technology (e.g. Aspirin against cardiovascular diseases).

Though technologies may evolve into another constellation, it is not our primary purpose to map the dynamics of technology development. Our main hypothesis is that each constellation demands a different set of user producer types because of the characteristics of technology and user population. By the same token, the dimension of phases is not added to analyse technology dynamics, but because some types of interaction are mainly relevant for the protected space, while others are for the wider world. These interactions could even take place in parallel or in iteration.

A final note concerns the function of a protected space for the different kinds of technology-user constellations, particularly for configurational technologies. Because for this type of technology, affordances and limitations are mostly shaped during the implementation of technology, a protected space hardly exists. Hence, Fleck (1994) emphasizes the importance of 'learning by trying' in these circumstances. In the case of ambiguous technology, in contrast, a protected space is of utmost importance to broaden the range of actors and aspects and to anticipate possible resistance.

In the next section we use the three dimensions to classify types of user producer interaction that we have identified in the literature on science technology and innovation.

Types of UPI

There is a growing literature that addresses user producer interaction (UPI) in technological innovation. This literature accommodates many insights about the different types of UPI, their objectives and their underlying assumptions about the circumstances in which these types are especially important. The literature is, however, divided in a number of different theoretical strands. Inspired by Stewart and Williams (2005) and Oudshoorn and Pinch (2003; 2008) we subsequently discuss evolutionary economics, technology assessment, social construction of technology, semiotic approaches and cultural studies. The types of interaction that we derive from these literatures are described in boxes 1 to 12. In these boxes we systematically evaluate the relevance of the UPI type alongside the three contextual dimensions that were distinguished in the previous section.

Evolutionary economics

Before turning to some specific insights into user producer interaction from evolutionary economics, it should be noted that any type of interaction presupposes adequate linkages among and between users and producers. Such linkages are getting stronger when they are frequently used. By interacting users and producers not only develop and improve linkages; they also learn to develop a common code or language for knowledge exchange (Lundvall, 1988; Lundvall, 1992; Kamp, 2002). This kind of learning by interacting is the first type of UPI (see box 1).

Box 1. Learning by interacting

Learning by interacting is a time-consuming process of establishing channels of information through which the message can pass and developing a common code of information to make the transmission of messages effective (Lundvall, 1988). Learning by interacting is relevant when information and knowledge are tacit and difficult to communicate. This is generally the case in protected spaces for technology development (Vandeberg, 2008). Moreover, learning by interacting is crucial in any case where frequent interaction is required, i.e. when actors have to rely on one another's expertise. Such reliance exists when designers of rigid technology are faced with heterogeneous users ('ambiguous technology') or when users with homogeneous needs are developing ideas about the most desirable configuration of flexible technology ('integrated systems').

Evolutionary economists have importantly contributed to the theory of user-producer interaction. They have conceptualized technology development in terms of variation and selection (Nelson & Winter, 1977). Competing variants of the same technology can live next to one another for some time, until a dominant design emerges (Utterback, 1994). Like in biological evolution, technology development is understood as an alternating process of trial and error in which the fittest survive. But unlike in biology the variation process is not completely blind. Innovators anticipate the selection environment (Van den Belt & Rip, 1987) and try to determine user needs and requirements in advance (Teubal, 1979). The concept of 'demand articulation' has been brought up in this context (Rip, 1995; Boon, Moors, Kuhlmann & Smits, 2008; Moors et al., forthcoming). Demand articulation is a learning process, because users do not have precise demands, needs and requirements in advance. This learning process is based on interactions between users and producers. Demand articulation is our second type of UPI (see box 2).

Box 2. Demand articulation

Demand articulation is "an iterative, inherently creative process in which stakeholders try to unravel preferences for and address what they perceive as important characteristics of an emerging innovation" (Boon, Moors, Kuhlmann & Smits, 2008). As a way to deal with the importance of uncertainty in the prediction of technological performance, demand articulation is especially relevant in early phases of technology development. An important function of many protected spaces is therefore to articulate demands. An exception can however be made for flexible technologies. Because these technologies can be configured on a custom base, demand articulation is mainly needed when the technology (or rather its components) is entering the wider world (Stewart & Williams, 2005, p. 205). With regard to the third dimension: demand articulation is relevant both when users are homogeneous and when they are heterogeneous, although demand is probably more univocally articulated in circumstances with homogeneous users and perhaps more focused on acceptability in circumstances of heterogeneous users.[1]

One of the main contributions of evolutionary economics to economics in general and to innovation studies is that it has opened the black-box of technology development that neo-classical economists have kept closed (Rosenberg, 1982). It does no longer treat innovation as an exogenous factor to explain economic growth, but scrutinizes the conditions for innovation themselves. One very important condition (by which variation and selection are coupled) is learning by using, especially if one takes into account that by far most innovations are incremental innovations. Learning by using can contribute to the optimization of performance, servicing and maintenance characteristics of capital goods (Rosenberg, 1982). It is the third type of UPI that we distinguish (see box 3).

Box 3. Learning by using

Learning by using “begins only after certain new products are used. […It] constitutes a feedback loop into the design aspect of new product development” (Rosenberg, 1982, p. 122/124). With examples from the aircraft industry Rosenberg shows that many performance characteristics of components (e.g. their lifetime) cannot be properly understood until after prolonged experience. R&D efforts insufficiently yield such understanding. This is especially the case with products characterized by a high degree of systemic complexity as for example in aircraft, electric power generation, telephones and computers, because the outcomes of interactions and contingencies in their user contexts cannot be precisely predicted. Learning by using is relevant in the wider world phase of technology development. It is relevant for any kind of technology as long as usage may reveal unexpected performance drawbacks, but especially when users are heterogeneous and expose the technology to diverse circumstances that cannot be fully anticipated in the protected space. Learning by using is a prerequisite for ‘innofusion’ (see below).

Learning by using typically leads to improvements of technology after producers are provided with important feedback. Yet, in some areas of technological development, users may also be actively involved in innovation and design beyond providing producers with important feedback. They come up with creative ideas for product development or even make improvement themselves. To capture this role of users as sources of innovation, notions like 'innofusion' (Fleck, 1988; Fleck, 1994) and 'user innovation' (Von Hippel, 1976; Von Hippel, 2005) are introduced. They refer to the adjustments to the technology deliberately made or initiated by users.[2] Innofusion and user innovation are the fourth and fifth types of UPI (see boxes 4 and 5)

Box 4. Innofusion

Innofusion is a contraction of diffusion and innovation (Fleck, 1988). It denotes the adaptations and improvements that users suggest or make when they implement technology into their local situation. Making use of the flexibilities in design users customize technology to their specific needs and create an optimal combination of affordances and constraints. Innofusion is especially relevant when technology enters the wider world in circumstances with heterogeneous users, because this situation calls for customized solutions. Innofusion requires flexible technologies that offer sufficient opportunities for adaptation and customization (e.g. changing components). Innofusion is thus a type of UPI strongly associated with configurational technologies (Fleck, 1988; Fleck, 1994; Stewart & Williams, 2005)

Box 5. User innovation

User innovation refers to the recognition of design possibilities, the exchange of innovation related information and the sales of user products *within user communities* (Von Hippel, 1976; Franke & Shah, 2003; Luthje, Herstatt & von Hippel, 2005; Von Hippel, 2005). That is: enthusiast and skilled users are dominant agents in all phases of the innovation process (Baldwin et al., 2006). Especially flexible, modifiable technology is suitable for user innovation, because of the multitude of design possibilities these offer (Franke & Von Hippel, 2003). Another favourable condition for user innovation is when the industry is very much oriented at (compromising) mass products despite a high level of user heterogeneity (Franke & Von Hippel, 2003). Under these conditions, demanding users are forced to design their own 'prototypes'. But user innovation can also develop in the case of homogeneous users: when industry has failed to recognize a need or design possibility. In this case, however, we expect that new manufacturers emerge or existing manufacturers try to appropriate the knowledge because of economies of scale. Then, user innovation will be restricted to protected spaces.

Technology Assessment

Technology Assessment started in the context of technology policy some forty years ago as an early warning instrument to assess the possible impacts of new technologies (Smits & Leyten, 1991; Smits et al., 1995; Schot & Rip, 1997). One of its most pronounced members, Constructive Technology Assessment (CTA), emerged at the crossroad of traditional TA and evolutionary economics. CTA strives after strategies to manage technological innovation while including both positive and negative impacts. It regards the couplings between technology variation and the selection environment as opportunities for constructive intervention. These interventions are justified by the insight that impacts are not fully determined by mere technological norms, but can be anticipated, evaluated and deliberately given shape, provided that this happens in an early phase when different directions for development are still open. CTA is a proactive, user oriented and interactive approach to technology development (Schot, 1992; Rip et al., 1995; Smits, Leyten & Den Hertog, 1995). Apart from demand articulation, it strives after two complementary ideals: the broadening of the perspectives of actors and the enriching of their understanding of the dynamics of technology development (Rip & Schot, 2002; Van Merkerk, 2007). Broadening and enriching are the sixth and seventh types of UPI that we discern in the literature.[3]

Box 6. Broadening

By broadening their perspectives, actors involved become aware of how technologies might affect others, and are stimulated to address societal questions and to accept a shared responsibility for sometimes barely predictable outcomes (Schot, 1996). Broadening is defined as “widening the perspectives of actors in terms of identifying a broader set of actors and aspects” (Van Merkerk, 2007, p. 42). This, for example, happens when a CTA practitioner develops scenarios of possible developments (see also enriching) and brings together in a workshop a set of actors implicated in one or more of these scenarios to discuss what their roles in the innovation process are or can be (Van Merkerk, 2007). Broadening is very relevant in protected spaces for technology development. Broadening can enhance (public) support for technology. It will therefore be important when technological actors are confronted with heterogeneous users, like in the construction of new infrastructure or electric power plants or the development of generic (e.g. nano) technology. Broadening seems relevant in cases of flexible technology, but crucial in cases of rigid technology.[4]

Box 7. Enriching

Enriching refers to the enhancement of actors' capacities to contribute well-considered and effectively to decision-making about technology development. It is defined as "increasing the understanding of actors in the complex dynamics of innovation processes and their role therein" (Van Merkerk, 2007, p. 42). In evolutionary economic terms enriching involves adequate understanding of the couplings between variation and selection, but actors could also draw on other theoretical approaches to enhance their understanding of the dynamics of innovation. Designers, analysts and user groups often make use of scenarios for enrichment (Rip & Schot, 2002). In this way, enriching is strongly associated with demand articulation and, if scenarios also raise new societal questions, it is an important source for broadening (e.g Van Rijswoud et al., 2008). Like broadening, enriching is very relevant in the protected space phase of technology development, because then there is a need to identify appropriate loci and means for intervention (Rip & Schot, 2002; Van Merkerk, 2007). Generally speaking, enriching is relevant for any kind of user technology constellation in this phase. There is, however, an argument why in the case of configurational technology enriching is somewhat less important for effective innovation. In that case innovation might mainly take place by creative users who have access to the means to customize technology, but who not necessarily have to understand how these means were produced (Stewart & Williams, 2005).[5]

Social Construction of Technology

The evolution of technology development has also been studied from a sociological point of view, thereby stressing the social nature of selection between technological options. How is it possible that options, which are not the most optimal from a technological point of view, are nevertheless selected? The Social Construction of Technology (SCOT) approach explains the emergence of dominant designs as the closure of societal debate in which artefacts that are initially characterized by high 'interpretative flexibility' gradually acquire a more fixed meaning ('closure') when consensus is achieved about problem definitions and appropriate solutions (Pinch & Bijker, 1987; Kline & Pinch, 1996). Social groups (institutions, organizations, as well as organized or unorganized groups of individuals) negotiate the meaning of technology in stakeholder meetings, markets (including advertisements), public debates, experiments and demonstrations, as well as in actual use (Pinch & Bijker, 1987; Kline & Pinch, 1996). A crucial element in the closure of technological controversy is the increased sharing of a technological frame around a certain artefacts. Frame sharing means that interactions move actors in the same directions and, as a consequence, relevant social groups establish a consensual frame and a dominant meaning of the artefact (Bijker, 1995). Frame sharing is the eighth type of UPI that we discuss.

Box 8. Frame sharing

A technological frame both emerges from and structures the interactions among the actors of a relevant social group. It consists of goals, key problems, problem-solving strategies, theories, tacit knowledge, testing procedures, design methods and criteria, users' practice, perceived substitution function, and exemplary artefacts. When actors are sharing these elements, then a technological frame emerges 'around' an artefact. Frame sharing is relevant in the protected space for technology development, when frames and meanings of emerging technologies are not yet stabilized, there is much interpretative flexibility[6] and social groups interpret technology with reference to diverse other frames of technologies, which they are already familiar with. With regard to the heterogeneity of users: the more heterogeneity, the more variability of interpretations, and the more important frame sharing. Frame sharing is relevant for both rigid (dikes) and flexible technology (bikes), though in the first case there is generally one frame that is accepted or not, while in the second case different frames may live next to one another for some time (Bijker, 1995) or longer.

A related type of UPI is frame adding. Adding a new frame to an existing one involves the reinterpretation of an artefact for which there is already an established market. Kline and Pinch (1996) discuss how the automobile in rural America was adapted and reshaped as a source of power within the frame of farm business. This reinterpretation of the T-ford as a traction engine not only neutralized a quite common interpretation in rural areas of the automobile as a dangerous 'devil wagon' compared to the safer horse and buggy, it also gave rise to the development of several accessories, like kits that took power from the crankshaft or rear axle. These kits turned the automobile into a useful machine "consisting of tractor-like drive wheels, a heavy axle, reduction gears to lower the speed to about three miles an hour [in order to] pull plows, harrows, mowers, binders, and other implements in the field" (p. 787). With this example Kline and Pinch show how users, who are oriented by another frame, adapt established products to their own situation. Frame adding is the ninth type of UPI.

Box 9. Frame adding

Frame adding means that new social groups reinterpret and adapt already stabilized technologies to their specific needs (Kline & Pinch, 1996). This type of UPI is not discussed in detail because of its similarity with innofusion: frame adding is also relevant in later phases of development, in cases of flexible technology and heterogeneous users. We do mention it separately, however, because the concept is brought forward in a different theoretical context and this might have implications for the understanding of social, economic and organizational conditions for successful frame adding (as this is a topic for further research).

Semiotic approaches

Semiotic approaches also emphasize the ‘interpretative flexibility’ of technological artefacts when they consider technologies as if they are texts, but these approaches rather elaborate on the consequences of this flexibility for the configurational work of technology developers. Designers and engineers somehow have to deal with diverging technology interpretations by users. In a case study of usability trials, Woolgar (1991) has shown how innovators observe users’ confusions, mistakes and other possible interpretations in order to take measures to constrain the degrees of freedom and teach people how to use the technology. Innovation is henceforth conceived of as a process of ‘configuring the user’, a process of delimiting the range of possible interpretations.

Box 10. Configuring the user

Configuring the user means “defining the identity of putative users, and setting constraints upon their likely future actions” (Woolgar, 1991, p. 59). While this definition suggests that producers force users into a certain role, Mackay (2000) insists that organizational and extra-organizational aspects also influence the interaction between producers and users and that the direction is much more bi-directional than Woolgar suggests. Nevertheless, the concept still denotes the necessary encouraging and teaching of users who are interested in exploring the opportunities of new technology.

Configuring the user is important once first users are recruited and technologies enter the wider world. While this phase dimension is relevant, it does not matter whether demand is heterogeneous or not or whether technology is flexible or not. The exception is again the combination of flexible technology and heterogeneous demand (configurational technology), when engaged users are actively involved in innovation processes (innofusion/frame adding). Configuring the user delimits the space to manoeuvre that users precisely need for innofusion.

A variant of the text metaphor is the film script metaphor. This metaphor strongly emphasizes how designers inscribe certain representations of and preferred actions for users into the technical content of artefacts, which suggest or prescribe how these artefacts could or should be used {Akrich, 1992 #16; Akrich, 1995 #14. For example, non-standard plugs and screws do not allow reparation of a broken device by lay people, but instead foster users to return it to the manufacturer. But how do designers construct adequate representations of users? How do they determine the needs and capacities of users? Akrich mentions six representation techniques ranging from designers' own imagination to market research and feedback. The process of user representation is of interest for our purposes, because it is a way for producers to deal with the uncertainty on the demand side when products are radically new and there is no established market yet. User representation is the eleventh type of UPI.

Box 11. User representation

User representation is the outcome of "techniques employed by system designers to construct and then appropriate […] representations (in a cognitive and political sense) of what the supposed users are and what they want" {Akrich, 1995 #14, p. 168}. While user representation via spokespersons is a necessary condition for many other types of UPI, in certain circumstances it is an objective of UPI itself. When users are heterogeneous, representativeness cannot be taken for granted. Especially in the case of rigid technology in a protected space for development, this constitutes a problem. In this situation, designers need to make choices that are difficult to reverse but that nevertheless determine the destinations of new product and hence success or failure. A solution for this problem is the construction of specific and adequate user representations that provide an orientation for designers when they have to make decisions.

Cultural studies

Cultural studies focus on user technology relations from the viewpoint of users as consumers. They show that new technology becomes a factor in the rearrangement of social and cultural differences, which in turn affects how users embrace or resist the technology. Cultural studies show that users do not simply accept or reject innovative technologies, but have to 'domesticate' them. Domestication of technology refers to the practices and consequences of incorporating novelties in daily lives (Silverstone & Hirsch, 1992). The history of the Sony Walkman provides an illustration. Du Gay et al. (1997) have shown how the technology became smaller, more robust and waterproof, depending on being used for in trains, running, or even in swimming pools and showers. Not so much the technology itself, but its domestication, familiarization and integration into the daily lives of users amounted to reshaping the joy of running and social relations within trains, while individualising music taste and opening up new markets related to music recording. Domestication involves the generation and reinforcement of common languages, visions and metaphors via commercial advertisements, ‘what’s new’ pages in magazines, public debates, social talk, art and literature, and – perhaps most importantly – in the claims and statements implicitly expressed by actual modes of usage.

Box 12. Domestication

Domestication is an active process in which the very meaning and use of new technologies are (re)shaped, and, consequently, the social identity of users themselves when users integrate novelties into their daily lives and social relations (Silverstone & Hirsch, 1992). Domestication is important for any kind of technology in any kind of user population, but specifically in the wider world phase of development. The concept of domestication is complementary to configuring the user: users are taught, but also actively learn how to use and give meaning to new technology in relation to their specific circumstances.

A typology of user producer interaction

The purpose of this paper is to review the literature in order to construct the main arguments why certain types of interaction are important and in what circumstances. These circumstances are defined by the heterogeneity of demand, the flexibility of the technology, and the phase of technology development. Table 2 summarizes the findings of the previous section alongside these three dimensions.

		User population			
		Homogeneous		Heterogeneous	
		Protected space	Wider world	Protected space	Wider world
Technology	Rigid	Demand articulation Enriching	Learning by using Configuring the user Domestication	User representation Demand articulation Broadening Enriching Frame sharing Learning by interacting	Learning by using Configuring the user Domestication
	Flexible	Demand articulation Learning by interacting User innovation Enriching	Demand articulation Learning by using Configuring the user Domestication	Demand articulation Broadening Frame sharing User innovation	Demand articulation Learning by using Innofusion User innovation Frame adding Domestication

Table 2: A classification of user-producer interaction

Each cell in the scheme represents the type of UPI that should be paid attention to in a case with characteristics that resembles those of the cell. We do not imply that each case of technological innovation will exactly fit in one of these cells. Because the distinctions on the axes represent extremes on a spectrum, cases may very well have to be positioned in between cells or shifting from cell to another cell over time. Still, we think the classification scheme is indicative for the types of UPI relevant in particular circumstances. Neither do we imply that the scheme should be read as a checklist. It is based on reasoning, meaning that each case requires its own reasoning, but we think that the scheme can be helpful as a way to structure the context of such cases from a UPI point of view.

To illustrate the potential value of the classification scheme, and to make the rather abstract theoretical notions more comprehensible, four examples of innovations with different technological and user characteristics are discussed: the refrigerator, clinical anaesthesia, video cassette recording, and the bicycle. These examples are based on existing and well-documented case studies. The classification scheme is used as a new window on these cases. Inevitably, this yields an incomplete and biased interpretation, but the main result of our study is not empirical but conceptual. We use the cases for clarification of the scheme.

Each case is introduced in terms of the flexibility of the technology and the heterogeneity of users. Then, it is schematically shown how these technologies developed in terms of the classification scheme. Next, key factors in the development of the technology according to the literature are identified and, finally, it is shown how relevant UPI types highlight certain activities and interactions and how these interactions contributed to the key factors in the cases. Due to overlap between types of interaction, two or three types are sometimes discussed simultaneously. Types relevant in the protected space are discussed first, and types relevant in the wider world thereafter, though it was not always possible to clearly distinguish these phases.

Commodities: the case of the refrigerator

Commodities are rigid technologies, which are supplied without qualitative differentiation across a market segment. They are deployed in well delineated market segments and relatively uniform user contexts. Examples of commodities are mass products based on a specific working mechanism like matches, toothpaste or refrigerators, but also rigid technologies for smaller, well delineated market segments, such as functional foods, drugs or radar technology. To illustrate the types of UPI relevant in this situation, we selected the case of the domestic refrigerator.[7]

Although composed of a large number of components, the refrigerator is an example of rigid technology. Its working mechanism is similar across variations. A liquid, called the refrigerant, transports heat from the inside to the outside through a process of compression (or absorption), cooling, expansion and evaporation. Because the refrigerator can only perform in that specific way,[8] most machines for domestic use were alike and competition was mostly a matter of price and design style (Nickles, 2002). Another reason for the rigidity of design is that cost saving mass-production methods created a powerful disincentive to variety. Market surveys had learned that price was a crucial adoption factor, so producers chose to minimize costs rather than to develop alternative models for relatively small niche markets (Nickles, 2002).

The homogeneity of the user population is less self-evident as it was socially shaped as part of the history of refrigerators. Nickles shows that market researchers of leading manufacturers did not advocate tailoring refrigerators to different market segments. They considered middle-class American households homogeneous enough to attract with one ‘universal’ type of refrigerator. They recommended that pioneering manufacturer Frigidaire “determine the size and design most desired by the average consumer and use it to create a standard for the entire product line. Refrigerator models would then be differentiated by price and features, as consumers ‘stepped-up’ from the ‘stripped’ or ‘nude’ models” (Nickles, 2002, p. 704). Nickles also shows how this homogeneity of demand was shaped by the work of home economists, a professional class of mainly women who informed the general public about matters of health and hygiene, and industrial designers, who promoted certain models as a standard for modern households. Figure 1 shows how the development of the refrigerator fits in the UPI classification scheme.

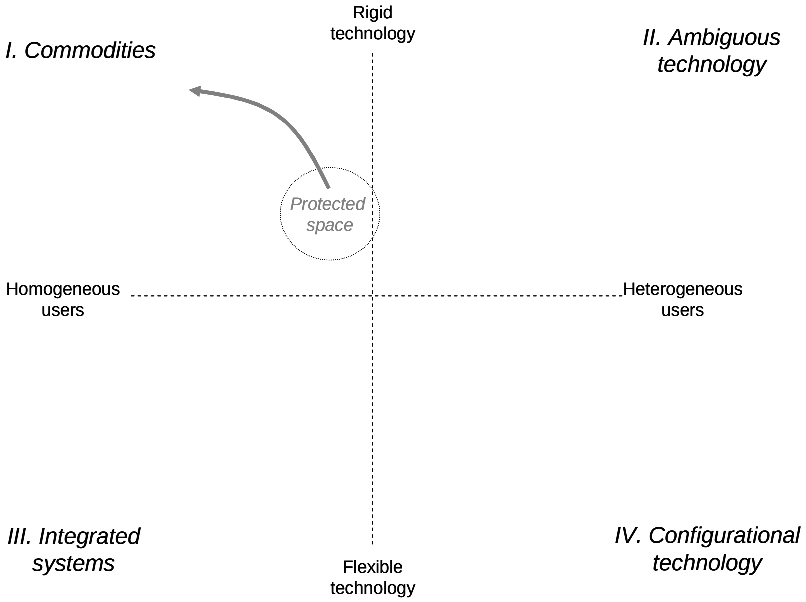

Figure 1. Development of the refrigerator

The figure indicates that the main issues in the protected space and the first years after market introduction were technological, such as finding the best refrigerant, designing reliable components, and sealing the system against leakage (Schwartz Cowan, 1985). The solutions found and incorporated in subsequent product cycles amounted to the path-dependency of the development process and hence the rigidity of the technology. This is indicated by the upward arrow. Over time, refrigerator models not only became cheaper and more reliable, but also more strongly associated with a widely promoted modern, middle-class way of life, the arrow bends to the left to indicate that large and homogeneous markets were served with relatively similar products.

In the literature a number of key-factors contributing to the development and diffusion of refrigerators from 1914 until the 1930s are described (Schwartz Cowan, 1985; Utterback, 1994; Robinson, 1997; Nickles, 2002):

- A growing market for ice and iceboxes familiarized many households with cooling as a way of food preservation;

- Mechanical refrigerators were already applied in ice-manufacturing, ice-conservation, ocean vessels, breweries, food storage, etc.;
- Investors were willing to lend money to domestic refrigerator entrepreneurs;
- Gas and electric utilities welcomed and supported refrigerator development;
- Producers soon learned to enhance technical performance (safety, reliability, noise reduction, size);
- Production costs significantly lowered (economies of scale);
- The design of refrigerators became ever better accustomed to the desires of a large middle-class market (simple, efficient, convenient);
- Home economists actively promoted a modern way of life among middle-class housewives, including values like hygiene, family care and food preservation.

User producer interactions have importantly contributed to some of these key factors. Existing iceboxes, to mention the first factor, informed entrepreneurs (and investors) in protected spaces about the likely role of refrigerators in future households. These boxes (wooden cabinets that were kept cool with blocks of ice) already embodied relatively new household practices of (weekly) shopping, food preservation, and the use of leftovers (Nickles, 2002). In other words, the growing demand for iceboxes represented the expected demand for refrigerators (Schwartz Cowan, 1985). This representation process is a mode of demand articulation in the protected space, yet a mode in which prospective users were displaced by existing products as a proper source of knowledge about demand..

Enhancing technical performance of refrigerators happened within the protected space, but continued through a process of learning by using after early models had entered the wider world. Main technical issues include size, weight, automatic control, reliability and safety. Issues like leaking tubes, malfunctioning compressors, broken thermostats and motors, and frozen pipes only became clear as lessons learned from prolonged usage. Their solutions were thus partly the result of learning by using.

During the 1930s, when most technical problems were solved, the design aspect received more attention and refrigerators became better adjusted to the tastes of users as a result of ongoing demand articulation in protected R&D spaces. These demand articulation processes were mediated by consumer research, analysis of competition, and retailers. For example, market researchers went door-to-door with scale drawings and models and even with a number of real refrigerators loaded on the trailer of a truck (Nickles, 2002). Several lessons were learned. Though design style was important, housewives particularly appreciated features like cleaning simplicity, efficiency, and convenience. Models inspired by an engineering logic were least attractive. For example, the Monitor-Top produced by General

Electric, a functionalist design with the compressor on top of the box, was a very efficient machine, that however did not appeal to consumer demand. A female employee of GE said: “It seems to me important that our engineers should realize that what interests them in such a product, that is, the machine itself, is the very thing that the woman buying it wants kept out of sight and out of mind” (quoted by Nickles, p. 713). Demands were thus mainly articulated in relation to existing refrigerator models, and mediated by market researchers, design consultants, retailers, and others who claimed to speak for housewives in general.

The work done by home economists and industrial designers (the last two key factors) strongly contributed to configuring the refrigerator user. Home economists, some of whom were employed by refrigerator producers, informed the public about values like hygiene and efficiency. They visited households to promote ideas of ‘scientific housekeeping’ and to remind women of their responsibility for the health of the family (Robinson, 1997). Industrial designers performed market research and translated their findings into the image of a ‘servantless housewife’, a model of the average user: a white, middle-class, married mother, living in single-family homes, who could no longer afford servants. By basing a more or less universal design standard on the socially constructed image of the average consumer, refrigerators came to embody values that typically belonged to middle-class households. In other words, promoting the refrigerator equalled promoting a middle class way of life. The white colour of refrigerator doors, which begged for keeping clean, reflected the importance of hygiene and proper food storage. “By buying a white refrigerator and keeping it in the kitchen, the housewife expressed her awareness of modern sanitary and food preservation standards; her ability to keep the refrigerator white and devoid of dirt represented the extent to which she met these standards” (Nickles, 2002, p. 705). Also the size and the interior, enabling saving money by buying milk, meat, and vegetables in bulk, reducing shopping trips, and using leftovers, reflected the middle-class way of life that was very appealing for those who could not afford servants (anymore). Hence, some advertisements promoted the ‘electric servant’ as a way to configure the refrigerator user.

The counterpart of user configuration is domestication. The configuration of the refrigerator user would not succeed if that user failed to appreciate and adopt the values and images inscribed in the technology and promoted around it. The notion of domestication draws attention to the attractiveness of the refrigerator as a means to distinguish middle-class from working-class families. “At the time when the middle class may have feared slipping to working-class status, and when popular culture portrayed the working class, immigrants, and nonwhites as having lower standards of cleanliness, these streamlined appliances suggested that women could maintain themselves and their family’s standards through thrift and hygiene.” In turn, the refrigerator was a carrier of meaning, an object lesson for the working class, as it taught middle class social norms and tastes.[9]

Although types of user producer interaction, such as demand articulation, learning by using, configuring the user and domestication, may not have been deliberately organized, the case of the refrigerator helps understanding how these processes *de facto* unfolded. Using these theoretical notions as a heuristic, moreover, illustrates how technology, users, and cultural contexts co-evolved, a phenomenon that is typical for many (successful) radical innovations.

Ambiguous technology: the case of clinical anaesthesia

Ambiguous technologies are rigid technologies with limited possibilities for adaptation. They are ambiguous because heterogeneous users with specific requirements have different and sometimes conflicting interests in the technology. Examples are roads, Aspirin, the pill or nuclear reactors. Ambiguous technologies are often surrounded by controversy, because of tensions between the non-malleability of the technology and the variety of demands and concerns. To illustrate this we use the example of clinical anaesthesia in nineteenth-century American surgery, which is carefully documented by Pernick (1985).

The heterogeneity of users has been fundamental in the early application of ether and chloroform as clinical anaesthesia. While these anaesthesia themselves were rigid technologies – the same substances were used, though in varying doses – different groups of surgeons and dentists attached diverging meanings to the new technology (Pernick, 1985). There were many opponents with fundamental objections, who considered anaesthetics as unnatural, as an inhibitor of the self-healing capacity of the body, as an encouragement of unnecessary surgery, or as a deprivation of the patient's autonomy during surgery. Moreover, anaesthesia was not without risks; some patients never woke up, anecdotes of wrong limbs being amputated were well known. The early days of clinical anaesthesia can be characterized as 'a house divided', accommodating two dominant groups of medical practitioners that both expressed fundamental objections against the use of anaesthesia: an orthodox group of medical practitioners advocated the old but widespread belief that pain is necessary, because it drives sickness away from the human body. The other group, comprising a diversity of sectarian practitioners (homeopaths, botanists, hydropaths, vegetarians) believed that the body would heal itself if environmental conditions like diet, ventilation and physical exercise would be favourable; risky (surgical) interventions in the body should be restricted to a minimum. Against all these fundamental objections, a third group of pragmatically oriented surgeons rapidly emerged. This group perceived objections against anaesthesia use much more in terms of disadvantages, risks, and reservations, which could be weighed against benefits and the need for anaesthesia.[10] But even within this group, diversity of attitudes existed as to which patients should be operated anaesthetized and which not, depending on surgeons' age, experience, humanitarian beliefs, religion, sexual politics, medical sect, work region, local pride, and public and private channels of communication.

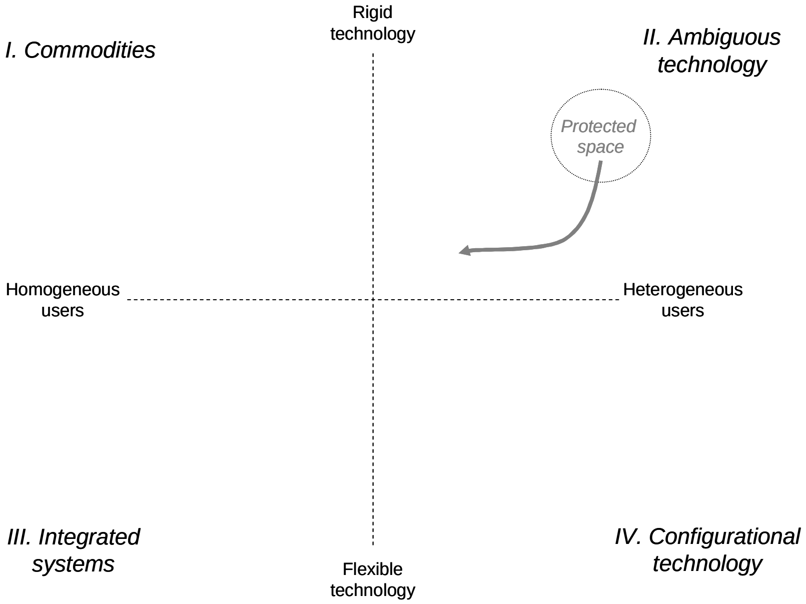

Figure 2. Development of clinical anaesthesia

Figure 2 represents the development of clinical anaesthesia. Initially, three relevant user groups associated anaesthesia with different meanings. The third group, who would bring anaesthesia to the wider world, adopted a pragmatic attitude and explored ways to vary doses depending on the sensitivity of patients and the kind of surgery.[11] This more flexible application of anaesthesia is represented by the downward arrow. The success of this approach, as indicated by the rapid growth of the third group compared to the other groups, is represented by the arrow turning towards more user homogeneity.

Pernick (1985) discusses a number of key factors responsible for the selective but growing use of anaesthetics. These key factors do not include the availability of ether and chloroform, because thanks to pharmaceutical pioneers (like Edward R. Squibb) improved and purified anaesthesia were readily available and affordable soon after their first introduction in 1846. Neither was patient demand a key factor. Patient demand by far exceeded the willingness of surgeons to use these new anaesthetics. Key factors rather concerned the reasons why the number of surgeons adopting anaesthesia, yet selectively, was rapidly growing in the face of resistance among orthodox practitioners and medical sects:

- The expression of anxieties and drawbacks by various opponents and benefits by advocates of (selective) anaesthesia marked the dilemmas around anaesthesia;

- A new pragmatic approach in medicine compromised orthodox and sectarian medicine by neither attributing primacy to Nature nor to Art. This pragmatic approach involved conceiving of (principle) objections as disadvantages, which could be weighed against advantages;
- Decisions to anaesthetize patients for surgery were the outcome of a calculus of risks and benefits in which individual differences with regard to age, race, sex, social class, nature of ailment, etc. were believed to determine pain sensitivity and response to anaesthesia;
- Procedures and rules were formulated to standardize therapies and to assist surgeons in their decision whether the operation should be performed anaesthetized or not;
- The application of statistics based on medical records of hospitals granted scientific legitimacy to these rules and procedures;
- The existence of professional associations (like the American Medical Association) – initially founded to provide institutional solidarity among orthodox practitioners facing medical sects – offered a platform for debating such procedures and rules (together with journal articles and surgical textbooks);
- The steamboat, railroad, and telegraph practically enabled participating in these national and regional associations.

User producer interactions have contributed to some of these key factors. The expression of principle objections to the use of anaesthesia can be denoted as a process of broadening. Like more often, broadening was the *de facto* manifestation of controversy because actors actively opposed a certain development (Rip, 1987). Broadening affected the adoption process in the sense that it forced the new pragmatists to include a wide set of aspects in their justification of using anaesthesia in a particular situation.

Closure of the controversy occurred through a process of frame sharing: the increased orientation on the same values, codes, guidelines, and visions of the future. Frame sharing mainly had effect on the second key factor – the incorporation of objections in a calculus of pros and cons. Initially, principle meanings associated with anaesthesia were derived from a variety of incompatible frames (orthodox heroism versus sectarian environmentalism). The new pragmatist approach included aspects of both frames. This approach turned into a frame itself, when statistically sound procedures and rules started to guide decision-making about the use of anaesthesia. Although surgeons within this frame still differed in weighing particular aspects, the new frame at least allowed for a reasonable debate in which ideology only played a minor role.

The differences within the new frame are highlighted by the concept of domestication. Some surgeons were stronger included in the frame than others: innovative young students, for example, were less reluctant to use anaesthesia than reactionary old professors. The frame had certainly not yet fully stabilized. But the other way around, domestication processes also contributed to the stabilization of the frame. For example, rules and procedures for the selective use of anaesthesia (to configure the surgeon) became part of more general notions of good medical practice. Domestication as the adoption of these rules, guidelines, norms and ideals contributed to the practitioner’s image as a medical professional as distinguished from a quack.

The formulation of rules and procedures and debates about these rules in journals and meetings of associations were the main effects of learning by using and learning by interacting. Learning by using involved the feedback of experiences with selective anaesthesia into the debates about guidelines. Much learning by using happened by statistical analysis of medical records of hospitals.

Learning by interacting refers to the development, maintenance and optimization of channels and codes for interaction. The case of anaesthesia took place in a context in which such channels and codes were already being developed, mainly thanks to the rise of new communication and transport technologies like the telegraph and railroads. Forums for debating standards and guidelines for the selective use of anaesthesia, such as medical (reform) conferences and special committees, were much more easily organized and new organizations like the American Medical Association were founded. Moreover, as rules, procedures, standards and guidelines were increasingly based on statistical knowledge (displacing prejudice), the stratification of patient populations provided the codes for interaction. Platforms and codes for debating medical guidelines were the outcome of a process of learning by interacting.

To conclude, the example of clinical anaesthetics well illustrates how theoretical concepts like broadening, frame sharing, domestication, and learning by interacting and using are relevant for understanding user producer interaction about ambiguous technology. The case also shows that most interaction processes occurred among users instead of between users and producers. The reason for this is that in the case of anaesthesia, processes of adoption and domestication were far more crucial than for instance investment decisions by producers. Consequently, due to this demand-side focus, UPI types like user representation and enriching, which emphasize user roles from the perspective of producers, do not appear relevant.

Neither does the distinction between a protected space and the wider world appear very relevant. A protected space, in which applications are not more than visions or diffuse scenarios, has never existed. Ether was not researched as an anaesthetic until shortly before the first (successful) experiment, after which each operation with anaesthesia remained another test case. Anaesthesia quickly entered the wider world, but remained very experimental.

Integrated systems: the case of video cassette recording

Integrated systems are configurations with an emerging generic identity which governs how components are integrated. A generic identity might emerge because homogeneous users articulate their demands in a converging way. Examples of integrated systems are mass market products like fashionable clothes, computer games and mass produced consumer electronics. In each of these examples, a multitude of design directions is possible from a technological point of view, but one dominant design finally turns out to offer the best fit for most users. Here we illustrate our findings with the well documented case of video cassette recording (VCR).

Due to its configurational flexibility, different types of VCR co-existed for some time between 1965 and 1975. Design options existed with regard to tape dimensions, number of heads, scanning method, track dimensions, tape and rotation speed, electronic circuitry, mechanical parts, etc. Between 1965 and 1970 eighteen prototypes were developed by nearly as many manufacturers, all configured differently (Deuten, 2003).

Yet, this flexibility would not last, because user demand was relatively homogeneous: “Typical for many artefacts, video recorders are made within factories and then shipped to customers. This creates an affordance for making configurations robust, so that they can operate reliably in a wide variety of contexts. At the same time, the application contexts were pre-structured, since television studios and, later, living rooms are rather uniform across the globe […] which made it relatively easy to anticipate on user contexts” (Deuten, 2003, p. 84-85). Rather than user demand, standardization would become the crucial success factor (enabling interchangeability of video cassettes).

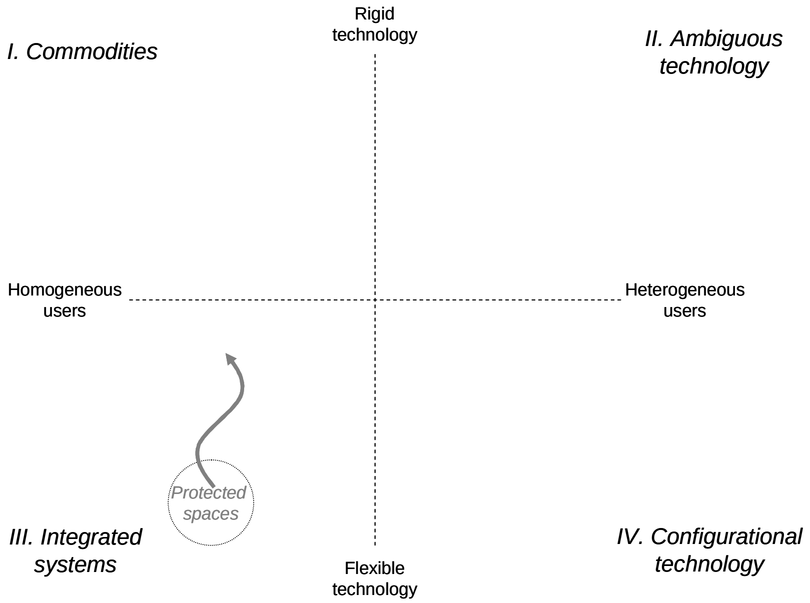

Figure 3. Development of video cassette recording

Figure 3 shows the development of VCR's as an example of an integrated system. The location of the protected space in the bottom indicates the large variety of design possibilities. At the same time, user preferences were fairly homogeneous and undifferentiated and directed all developments towards reduction of size, weight, inconvenience and costs compared to broadcasting video recorders. After a (protecting) collaboration with Matsushita and Japan Victor Company (JVC), Sony introduced its U-Matic in 1971, which was based on an agreed preliminary standard with regard to tape width, number of heads and (helical) scanning method (upward arrow). The U-Matic was successful on the market of schools and other institutions. However, to persuade consumers on the mass market the U-Matic still had too many limitations, such as size and weight of the machine, the size of the cassette and recording time. While the latter two problems created conflicting design requirements, Sony decided to focus on miniaturization of cassettes, and JVC (and others) on increasing recording time (the arrow in Figure 3 bends slightly to the right because of different *assumptions* about user preferences). In a standardization battle between Sony's Betamax and JVC's VHS system, the latter survived and nearly all others would in the end adopt the VHS standard (arrow towards upper left).

In the literature we found the following key factors that explain the course of events in the development of video cassette recording (Cusumano et al., 1997; Deuten, 2003):

- Basic technological concepts already existed: video recording (television broadcasting), miniaturization (transistors), and cassettes (audio);

- Manufacturers in the Electronics Industry Association of Japan (EIAJ) agreed on a standard format of a ½ inch, helical scan, one head, open reel video tape recorder;
- Sony introduced the U-Matic for schools and other institutions. The machine was still too large and expensive for home use;
- Sony, Matsushita, and JVC agreed to adopt the U-Matic format as the standard for the institutional market and signed a cross-licensing agreement that enabled Matsushita and JVC to incorporate patented U-Matic technology in their designs for home use;
- Matsushita invested in manufacturing capacity for mass production while it was waiting for innovative firms to introduce new products. In this way it would become an attractive partner later on;
- Sony failed to persuade RCA, the major American television manufacturer, and Matsushita to adopt the Betamax format and proceed with mass production for the American and Japanese markets;
- JVC introduced its VHS format to the market and meanwhile started to actively pursue licensing and Original Equipment Manufacturer (OEM) agreements with many Japanese and European manufacturers and distributers;
- RCA discontinued its own VCR project and waited for a company with sufficient production capacity for the American market. Matsushita successfully negotiated an OEM agreement with RCA;
- Suppliers of pre-recorded video tapes were persuaded to adopt the VHS format.

While Sony's Betamax had good chances from a technological point of view, it was JVC, later supported by Matsushita and most distributors in Japan, the US and Europe, that won the battle. For the purpose of illustrating the contribution of user producer interaction to these factors we focus on Sony's self-confidence and its consequent neglect of desires and trends in the context of use.

Sony failed to persuade RCA and Matsushita, because Sony had not sufficiently stimulated demand articulation. Based on the diffusion of television and VCR developments in the film industry, Sony was the first to envision a mass market for video recording. The film industry's technology, however, was still way too large and expensive for the consumer market. Miniaturization, i.e. reducing size and weight of both machines and tapes, was the main incentive for Sony's developments. But by predominantly focusing on this aspect of demand, Sony paid insufficient attention to other aspects. One of the initial shortcomings of Sony's first model of the Betamax was its 1 hour recording time. To foster demand articulation, American video pioneer RCA had just performed a market study, in which it had given 200 of its own VCR's to customers in the US, and concluded that recording time should be at least 2 hours (Cusumano, Mylonadis & Rosenbloom, 1997). Sony had omitted to perform such user research. Potential collaborators such as Matsushita, Hitachi, Sharp and Mitsubishi decided to wait for the VHS format with 2 hours recording time, which JVC announced some months later. Together with most European and American manufacturers, including RCA, they jumped on the VHS bandwagon.

Enriching and learning by interacting were closely related to Sony's failure and JVC's success in enlisting enough allies behind their VCR formats. Enriching refers to the empowerment of stakeholders for effective contribution to the direction of the development and production process. Sony, quite convinced of its own technology and production capacity, pressed commitment and reputation in the persuasion of potential partners to adopt the Betamax standard. In contrast, JVC (later together with Matsushita) showed more modesty and flexibility, because JVC needed others to be able to produce enough quantities for the different markets across the globe. Although gaining scope was the ultimate purpose of forming alliances, JVC also aimed at enriching others to improve the VHS standard, by providing assistance in manufacturing and marketing. Moreover, because such enriching was recurrent, it also contributed to learning by interaction. "Japan Victor [JVC] managers approached prospective partners in an exceedingly 'polity and gentle' manner, and encouraged them to adopt as the common VCR standard 'the best system we are all working on,' rather than the VHS per se. One outcome of Japan Victor's approach was that prospective manufacturing partners truly believed they would have some stake in the future evolution of VHS features. Allowing partners to share in development also improved the VHS in ways that Japan Victor might not have pursued itself" (Cusumano, Mylonadis & Rosenbloom, 1997, p. 16). Enriching thus importantly contributed to product improvement.

The diffusion of VCR due to the emergence of a video rental business and a growing availability of movies on tape draws attention to the process of domesticating video technology. The sudden possibility to watch erotic content in the privacy at home, for example, pushed the exponential growth of VCR ownership in the early eighties. Similarly, renting a video machine and some tapes for a child's birthday party or just organising a weekend of watching movies was a common practice in the mid-eighties (Roehl & Varian, 2001). Domestication of the video recorder as a home cinema thus contributed to its widespread diffusion.

Another reason why people adopted a VHS instead of a Betamax was that the VHS family succeeded to configure the home movie watcher as a VHS user. JVC's American partner RCA developed an important alliance with Magnetic Video Corporation (MV), a manufacturer of pre-recorded videos for education and training and the first company to offer feature films on cassette. RCA offered two free cassettes as well as a MV membership to all their VCR customers. In effect, demand for MV pre-recorded VHS tapes increased relative to Beta tapes and MV expanded capacity for producing VHS tapes. In 1980, VHS' share in cassette sales was estimated to be between 70% and 90% (Cusumano, Mylonadis & Rosenbloom, 1997).

To conclude, the case of VCR was selected to illustrate the relevance of types of user producer interaction like demand articulation, enriching, learning by interacting, domestication and configuring the user in the case of integrated systems. It shows how the much more interactive approach towards users and partners of JVC and Matsushita allowed them to gain a sustainable and winning position. They actively approached potential allies, allowed them to utilize the knowledge gained and did not consider its own prototypes as the best possible design, but remained susceptible for suggestions for improvement. The most important result of this 'strategic manoeuvring' was the de facto establishment of VHS as the standard for video recording (Cusumano, Mylonadis & Rosenbloom, 1997).

Configurational technology: the case of the bicycle

Configurational technologies are adaptable configurations composed of loosely coupled and changeable components. Configurational technologies can be applied in a diversity of user contexts, because they can be tailored to the specific desires, needs and requirements of users. Examples are computer software, robots, but also home made meals and bicycles. We take the development of bicycles as an example to explore user producer interaction in configurational technologies. Due to its configurational nature, the wide availability of components, and the relative ease of reparation or modification, the bicycle is a typical example of a flexible technology. The heterogeneity of users is reflected in the many different social groups that attached different meanings to the bicycle (Bijker, 1995) and in the variety of user communities and individual requirements that more specific cases like the mountain bike bring to the fore (Lüthje, Herstatt & von Hippel, 2005).

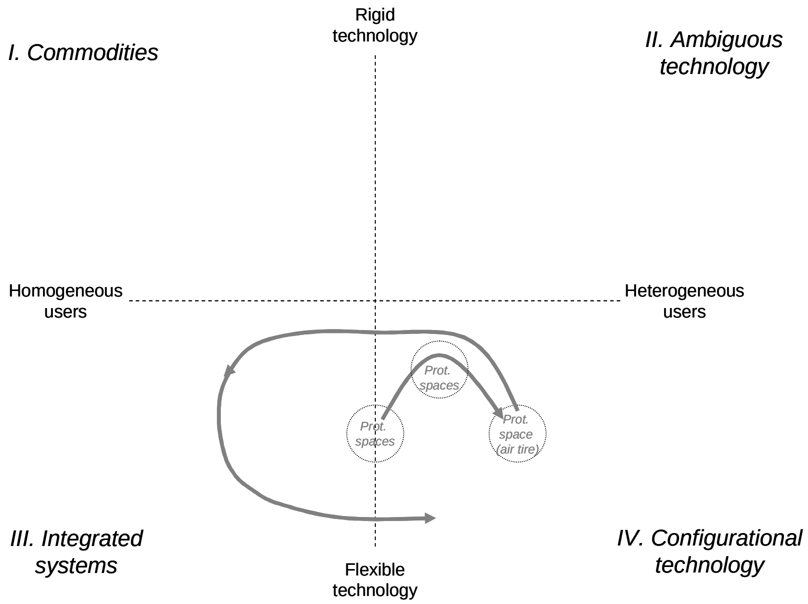

Figure 4. Development of the bicycle

Figure 4 shows the development of the bicycle over more than a century. Early bicycle development showed much variation (running bikes, rear driven, front driven, low-wheelers, high-wheelers, tricycles, etc.), each originating in their own more or less protected space.[12] While these variations were often the result of local activity of creative blacksmiths and hobbyists, most failed to become a commercial success. One exception was the high-wheeled, front driven, and relatively fast ‘Ordinary’. The Ordinary became the dominant design, especially among wealthy, young and sportive riders, who used the bikes to show off in parks and race against each other (upward arrow in Figure 4). Their use of bikes, however, also raised a lot of resistance and criticism. Users who wanted to ride one but could not, such as women and elderly, complained that the Ordinary was very difficult to mount and unsafe to ride (arrow bends to the right). For this target group manufacturers began producing lower bicycles, tricycles, dicycles, and ‘safety ordinaries’ (arrow goes down again). Until the application of air tires, different bicycles served different user groups. Equipped with air tires, however, low wheeled bicycle models turned out to be both safe and fast. This low-wheeler would evolve into the design still dominant today (leftward arrow towards integrated systems). The bike case continues decades later with a series of new product cycles, like race bikes, cross bikes, mountain bikes, and folding bikes. (We take these cycles in the maturity stage of the artefact also into account, because they were based on processes of innofusion and user innovation typical for configurational technology (Fleck, 1988; Fleck, 1993).) Bicycle components had become widely available for anyone who wanted to maintain or repair his own bicycle. This situation enabled more people to experiment with alternative configurations of bicycles, many of which indeed entered the market. This situation is represented by the return of the arrow to the area of configurational technology.

A number of key factors in this course of events are brought forward in the literature (Bijker, 1995; Lüthje, Herstatt & von Hippel, 2005):

- Many prototypes of bicycles were developed by local blacksmiths and carriage makers, some of which were also produced in larger quantities;
- Subsequent models solved problems posed by predecessors, while in their turn raising new problems to be solved;
- Manufacturers organized racing contests to demonstrate and promote bicycles, wheel diameter was enlarged to increase speed and create macho image;
- Resistance and criticism emerged against the unsafe nature of Ordinary bicycles;
- Low wheeled bicycles and tricycles were further developed to serve non-users of the Ordinary;
- Vibration problems of the low-wheelers were solved with anti-vibration devices like springs and air tires; developing and applying air tires in combination with indirect rear wheel drive appeared to offer the possibility to decrease wheel size without compromising speed;
- An industry for mass production of bicycles and components emerged;
- Different biking cultures adapted bicycles to their own specifications.

How did user producer interaction types contribute to these factors? In the early phase of development, until the late 1860s, most bicycles were fairly simple constructions produced by local blacksmiths and carriage makers. We conceive of this activity as user innovation, because these local producers stood very close to users or were main users themselves. The technology was very flexible, meaning that various designs were reasonably possible. In this situation, users were important agents in the creative process of idea generation and prototype construction. Examples of user innovations are the ‘fast-running machine’ (1817) by Karl Drais and the ‘hobby-horse’ (1839) by Kirckpatrick Macmillan.

With regard to the second key factor, the succession of variants, demand articulation and learning by using were important driving forces. One problem with the first wood-made ‘running machines’ was the impossibility of steering and keeping ones balance. While this problem was solved by adding and improving a steering mechanism, other problems remained, such as muddy feet due to the absence of treadles. Treadles with levers connected to the rear wheel then turned out to require great effort from the rider. These problems inspired the development of a solid wrought-iron front-driven vehicle with cranks directly connected to the axle of the front wheel. Subsequently, rubber rings around the wheels and higher front wheels were proposed to prevent the perceived problem of slipping and to increase speed for racing purposes, which around 1870 resulted in a relatively successful model that would become known as the 'Ordinary'.[13] In this process of bicycle development, demand articulation and learning by using about unanticipated aspects were indispensible, integrated activities. Moreover, as the insights gained from these interaction processes during the diffusion process were translated into specifications for improved design, a learning loop took place that is known by the concept of innofusion.

Bicycle manufacturers more than once organized racing contests to demonstrate the advantages of their product. Analogous to the usability trials described by Woolgar (1991) in his study about configuring the user, racing contests configured bicycle users as sportive macho men. In these contests, modifications contributing to manoeuvrability and speed, such as steering mechanism and wheel diameter, were presented as major innovations, whereas the unsafe aspects of some of these bikes were neglected or taken for granted. After all, accidents could be said to belong to the activity of racing, not to bikes as such. But racing contests targeted sportive men and henceforth failed to configure elderly and women, who did not bother about speed and who were not interested in contests. Other kinds of demonstrations (e.g. with women in dresses riding bicycles) attempted to configure the user of the safe bicycle. Configuring the user as sportive machos thus contributed to the stabilization of the macho bicycle, which is not the same as closure of the controversy between the macho and the unsafe bike (Bijker, 1995).

When pedestrians, women, elderly and other typical non-users of the Ordinary started to articulate their concerns and demands, the heterogeneity of users increased. The debate was broadened with aspects of safety and comfort. Consequently, other models such as tricycles, lower ordinaries, and low-wheeled chain driven vehicles were proposed as solutions for the safety problem and these models co-existed with the Ordinary for some time. This is not an unusual situation in circumstances of configurational technology. In this case, however, the introduction of the air tire finally gave 'safety bicycles' a decisive advantage. Frame sharing took place when striving for speed and the striving for safety – initially part of two different frames from which users evaluated the characteristics of a technology – became part of one single frame. Equipped with 'high speed' air tires instead of energy consuming anti-vibration springs, low wheelers were both safe and fast. The merger of frames thus incited a common orientation for further innovation.

Over time, an industry for mass production of bicycles as well as components (saddles, tires and the like) emerged. Next to this, local blacksmiths and mechanics continued to produce small numbers of bicycles against competing costs. Most bicycles shared a similar design based on the historical outcome of a social construction process. Yet, some niches existed for special, more expensive, 'de luxe' bicycles, both produced by special departments of factories and by local workshops (Bijker, 1995).

Nowadays niche markets exist for mountain bikes, race bikes, folding bikes, electric bikes, reclining bikes, and beach bikes. The mountain bike in the 1970s is a nice example for illustrating the different types of user producer interaction in later phases of bicycle development. Demand articulation, frame adding and user innovation appear to be relevant in this phase. In the early 1970s, groups of some young cyclists began using their bikes off-road, but because commercial bicycles were not suited for this kind of use, they constructed radically new 'clunkers' themselves: strong old bike frames with balloon tires to which they added motorcycle lever-operated drum brakes for better stopping ability (Lüthje, Herstatt & von Hippel, 2005). These bikes were subsequently produced by small specialized manufacturers, soon followed by major bike manufacturers. Yet, because new user groups used the off-road bikes in various more or less unexpected circumstances, including mountains, ice, house roofs, and water towers, ever new demands were articulated. When such demands were too specific, users made adaptations and incremental improvements themselves. Lüthje et al. mention examples such as 'anti-spin foam rings' for pedals on stunt bikes, 'winter tires' on ice bikes and a 'thumb-activated stopwatch' on a training bike. These user innovations are oriented by other frames (stunting, ice biking, performance measuring) that are added to the dominant frame of mountain biking. This possibility of frame adding also shows that bikes are essentially unfinished until they are fully domesticated. The concept of innofusion emphasizes that innovation is henceforth a function of the diffusion of mountain bikes.

To conclude, the bicycle is an interesting case of configurational technology. A dominant design emerged from a variety of possibilities in an early phase because demand was just developing, but over time and with the standardization of components, more active involvement of users also became possible. Types of UPI, such as user innovation, demand articulation, learning by using, broadening, frame sharing, and innofusion, appear to be relevant for understanding this development process.

Conclusions and discussion

Innovation processes take place in complex networks or systems of innovation, in which producers and users depend on each other's knowledge and capacities. Such context dependency is especially strong when new technological opportunities are just emerging and there is uncertainty about technology, demand, and ethical, legal and social implications. User producer interaction is indispensable in these circumstances. Users have to learn how to assess the use-value of new technology, to articulate needs and concerns, to intervene in important design decisions, to get technologies to work, to adapt technologies to their specific circumstances, and to establish effective modes of interaction. Producers have to learn what users want, how new technologies fulfil such wants, how to deal with concerns and resistance, how to cooperate with users, how technologies perform in a user context, whether interfaces are clear, whether users are capable of adjusting technology to their needs, what adaptations should be made, and how to receive such feedback at all. Different types of user producer interaction serve this variety of objectives.

In this research we have identified twelve different (though sometimes overlapping) types of user producer interaction (UPI) in the literature on science, technology and innovation. The relevance of these types of interaction depends on their contexts. We have conceptualized the context of interaction by means of distinctions on three dimensions, i.e. the phase of technology development, the flexibility of technology, and the heterogeneity of users, and evaluated each interaction type along these dimensions. The main results of this conceptualization are a distinction between four user-technology constellations – commodities, ambiguous technologies, integrated systems and configurational technologies – and a classification of the UPI types most relevant for these constellations. To illustrate the potential value of the classification, four examples of innovations with varying technological and user characteristics are explored: the refrigerator, clinical anaesthesia, video cassette recording, and the bicycle. For each example the relevant UPI types are discussed and it is shown how these types highlight certain activities and interactions during key events of innovation processes. Moreover, the case studies also reveal the relations and overlap between types of interaction that were derived from different theoretical literatures.

Single case studies are performed for the purposes of illustration. Future research should comprize more case studies in the variety of circumstances. Such research should learn whether the hypothetical classification of UPI types as based on the theoretical literature and our own reasoning is right. Moreover, since this research was limited to the types of UPI in different circumstances, much more can be learned from future research about the particular forms, mechanisms and conditions for effective user producer interaction. In this way, the classification offers an outlook on developing a ‘toolbox’ for organising and managing user producer interaction in context.

We will end this paper with bringing up a number of comments and reservations on the utility of the proposed classification in the context of the four cases of technological innovation.

First, because the cases were primarily selected to illustrate the type of interactions in a particular context, they are not necessarily examples of effectively organized and managed interactions. Case studies thereof, however, will be required for learning about the conditions and mechanisms leading to effective interactions.

Second, these cases more or less fitted the four quadrants of the classification scheme (Table 2). However, some technologies may have properties of more than one ‘ideal type’ and should be positioned somewhere in the middle of the scheme. Technologies may also transform from one type into another over time. The bicycle could serve as an example, here. When a shared frame between heterogeneous users emerged, the bicycle entered the area of integrated systems. Later, when users started to explore alternative uses of bicycles, demands again started to diverge and become more heterogeneous. A similar ‘life cycle’ can be observed in many ICTs (Stewart & Williams, 2005).

Third, the case studies show that types of interaction are often overlapping and one type may even become embedded in another. For example, the domestication of the refrigerator comprised an element of demand articulation when the importance of the refrigerator in displaying a middle-class way of life became increasingly articulated. Also the broadening of debates about the meaning of bicycles came about through articulations of heterogeneous demands.

Fourth, the dimension of user heterogeneity is a contextual factor that does not remain unaffected by the interactions taking place. For example, the homogeneity of American middle-class refrigerator users was in part the outcome of reformation work, industrial design, and marketing. Especially the concepts of configuring the user and domestication draw attention to the social shaping of user communities.

Fifth, in the case studies we encountered important roles for different kinds of institutions such as patents, regulation, and professional norms. Patents, for example, appeared crucial in the video cassette recording case, because they offered manufacturers an attractive position in negotiations about cross-licensing and OEM agreements. Professional associations, norms and guidelines featured prominently in the anaesthesia case, because by means of these institutions a rational way of deploying anaesthesia became shared among surgeons. The role of such institutions was not spelled out completely in our endeavour to put UPI in context, but is of course highly relevant when UPI is deliberately organized in a real life context.

These five comments imply that the idea of a ‘toolbox’ should not be taken too literally; the ‘tools’ will need to be interpreted in relation to the specificity and contingency of particular technologies and markets. Nevertheless, our research offers an analytic scheme to unravel the various processes of user producer interaction and to contribute to the understanding of underlying mechanisms of innovation processes in different contexts. Hopefully this scheme supports analysts, policy makers and practitioners to contextualize innovation processes and to sensitize them to relevant types of UPI in those contexts.

Notes

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[1] Rip (1995) bases his conception of 'demand articulation' largely on Teubal's (1979) work on 'need determination' but makes two important contributions regarding the articulation of demands for ambiguous and/or costly technologies. Firstly, he points to the importance of involving spokespersons or representative organizations (like consumer or patient organizations), who are usually better organized and informed than actual users and have better access to protected spaces for technology development. Secondly, Rip argues that the articulation of concerns has become more important in addition to the articulation of needs. Demand articulation should therefore be supplemented with acceptability articulation.

[2] This view on the agency of users should not be conceived as a democratic solution to technocratic tendencies in the context of design, as Von Hippel (2005) seems to suggest. Democratization encompasses much more than merely user innovation (Nahuis, 2007). Moreover, suppliers often succeed to appropriate the knowledge generated by users in due course and readdress the same issues more effectively in the context of design.

[3] Van Merkerk (2007) develops six effect indicators that stand proxy for broadening and enriching: enhancing knowledge, changing attitudes and opinions, initialized actions, anticipation, reflection, and learning. He combined these indicators to determine whether broadening and enriching changed the thinking, acting, and interacting of actors, but also admits that, although broadening and enriching are different things, it was difficult to assess the two effects separately in the evaluation.

[4] Following Gibbons, Smits (2002) relates the growing importance of broadening to a transition from 'weakly linked systems consisting of discrete components' to 'strongly-linked systems consisting of fuzzy components'. In the latter "success and failure are strongly associated with the ability of all parties concerned to form wise alliances and – partly thanks to this – on the ability to mobilize and use the creative potential of users to improve the innovation process" (p. 869).

[5] See box 4 (innofusion), 5 (user-led innovation) and 13 (domestication).

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[6] Note that interpretative flexibility is not the same as flexible technology. Interpretative flexibility is rather a characteristic of user heterogeneity, and the consequent variety of problem definitions and demands that users experience in view of emerging technology.

[7] In this paper we do not discuss the very first phase of mechanical refrigeration. See Utterback (1994) for the transition of harvested ice to manufactured ice and the adoption of ice machines in restaurants and cruise ships.

[8] The absorption refrigerator is perhaps an exception. In her study about corporate strength, Schwartz Cowan (1985) describes the principle differences between a gas fired absorption refrigerator and an electrical compression refrigerator. Gas refrigerators were more silent and therefore perhaps more attractive. However, gas refrigerator producers never really acquired a sustainable market position, mainly because they were not sufficiently large, powerful, aggressive and resourceful compared to producers of compression refrigerator. Consumer preferences hardly played a role in this process.

[9] An altogether different example of domestication of the refrigerator is given by Watkins (2006), who shows how refrigerators are generally domesticated as bulletin boards and displays for children’s art or photographs related to their design and place in the kitchen.

[10] In retrospect, this pragmatic utilitarian approach to innovation seems much more self-evident than it was in those days: “In today’s world, where cost-benefit analysis is a profession in itself, routinely used to decide questions from drug safety to war and peace, it may be hard to recapture how radically the calculus of suffering revolutionized the techniques of professional decision-making in medicine” (Pernick, 1985, p. 122).

[11] For example, because of their high sensitivity, anesthesia was indicated for children, women and educated, upperclass white patients. Lower class patients, Afro-Americans and war veterans were contra-indicated. The type of surgery also mattered: amputations, broken bones, and lengthy surgery should be done anaesthized, while brain, heart and lung surgery, birthgiving, and nails, toes, throat, eye or anus surgery should be done unanaesthized. And although there was of course also a grey area in between, in any case a careful calculus of suffering and safety should have been made (Pernick, 1985).

[12] For pictures, see http://www.cycle-info.bpaj.or.jp/english/learn/chistory2.html. This overview, however, is far from comprehensive: in 1886 alone one could choose between 89 different bicycles and 106 tricycles in the UK (Bijker, 1995).

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[13] This short summary admittedly reintroduces an assumption of linearity that Bijker (1995) carefully circumvents in his historical account. See his book for a more evolutionary account that puts failing variants at an equal footing.

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