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User producer interaction in context

Abstract

Science, technology and innovation studies show that intensified user producer interaction (UPI) increases chances for successful innovations. It is not always clear, however, what type of interaction is necessary in a particular context. This article identifies seven different types of UPI: constructing linkages, broadening, characterizing users, upstream involvement, first user enrollment, feedback, and downstream innovation. Specific contextual conditions from which these UPI types derive relevance are discussed. The material dimension of this context is conceptualized on the base of a distinction between types of technologies that differ in the degree to which they are customizable to user demands. Four case studies of different types of technologies show that technological characteristics indeed matter for UPI, as do the heterogeneity of users and the phase of technology development.

Keywords: Innovation, user producer interaction, technological flexibility, user heterogeneity

1. Introduction

Innovation studies show that intensified user producer interaction increases chances for successful innovations [1]. Producers are interested in societal acceptance of their products, in access to users' knowledge and in mobilizing the creative potential of users [2,3]. 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 [4-8]. 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 wrap together the results of these studies and bring some order in the variety of what we call 'types of user producer interaction', by identifying types of interaction and arguing that different kinds of contexts demand different types of interaction.

The concept of user producer interaction has been coined by Lundvall [5] to denote interaction processes that form the backbone of innovation systems. In a pure market, in the neo-classical sense, only information about existing products (price, volume) would be exchanged and innovative activity would be rather exceptional. In contrast, in innovation systems also information and knowledge about potential user needs and usability of new products are exchanged. The systemic nature of innovation implies that needs, customer values and trust are produced and diffused through organisational links between different subsystems. Moreover, because users and producers not only develop, but also optimize information channels, develop a common language for knowledge exchange and develop mutual trust, learning by interacting leads to stronger user producer links within innovation systems. Especially in cases where either technological characteristics or user demands are highly complex and uncertain, strong organizational links are to be expected.

Innovation systems consist of interconnected institutions to create, store and transfer the knowledge, skills and artefacts which define new technologies [9]. They contain individual or organizational users, industrial firms, universities, research institutes, infrastructures and various kinds of intermediaries (see figure 1). Our focus is on relations between industrial firms (producers) and users.[1]

<< Figure 1 about here>>

Figure 1. Schematic representation of an innovation system

Producers of technology are firms that transform knowledge, skills and artefacts into products or services to be offered to the marketplace. Producer firms can be divided in four categories according to Pavitt's [10] taxonomy: supplier-dominated firms (e.g. textile, agriculture), scale-intensive firms (e.g. basic materials, consumer durables), specialized suppliers (e.g. high-tech instruments, machinery), and science-based firms (e.g. pharmaceutical, electronics). This distinction is among other things based on different user requirements. Characteristics of sectors thus matter in the way firms relate to and interact with users [11]. In this article, however, we do not explicitly address this factor, because we want to emphasize other dimensions that have received much less attention in the literature.

Users are individuals, groups of individuals or organizations that employ products or services to fulfill a particular need or, in a broader sense, transfer knowledge about usability or user

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[1] According to Lundvall [5] user producer interactions are not exclusive for the product markets. Even in basic science there are user producer interactions, although users of science are often scientists too.

needs. Accordingly, there are different sorts of users. Proxy users are people who are representative for a larger group of anonymous end users. Lead users are people who are representative for future users. Instead of interacting with large groups of end users, innovating producers often recruit proxy or lead users for usability trials and early adoption [12, 13]. Another distinction is between intermediate and final users. Intermediate users, for example physicians and pharmacists in the case of pharmaceutical drugs, function as knowledge brokers between final users and producers. One could furthermore distinguish between different institutional forms of users, like (lay) consumers, professional users, or the government as client. Partly, but not necessarily, coinciding is the distinction between users as co-producers and users as implicated actors. The first are active agents in technological development, whereas the latter are affected by technology but rather invisible during its development [14]. These distinctions appear particularly relevant when discussing user roles implied in different types of user producer interaction.

The characterization and agency of producers and users also depends on the level of technological detail. Disco et al. [15] distinguish between four levels: components (materials, nuts and bolts), devices (pumps, engines), artefacts (refrigerator, bicycle), and systems (transportation system, electricity network). It is important to keep these differences in mind, because a user at the level of components or devices might be a producer at the level of artefacts. A firm interacting as user with a science-based firm, might interact as producer with a scale-intensive firm, being a specialized supplier itself. To avoid confusion, we focus on producers and users at the level of artefacts, without excluding that our findings also apply to other levels. When referring to technology as artefacts, we do not mean that knowledge, skills and techniques are irrelevant. Regardless of level, technologies are configurations that work only because of the interplay between these technical and contextual elements [16].

Having situated processes of user producer interaction (UPI) about technological artefacts in the context of an innovation system, the paper is structured as follows. First seven different types of UPI are introduced. Then, the specific contextual conditions in which these UPI types are relevant are discussed. These conditions include the type of technology, the phase of technology development and the heterogeneity of users. The next part elaborates on four exemplary case studies to illustrate the UPI types in their particular context. The paper ends with a conclusion and discussion.

2. *Types of UPI*

There is a growing literature that addresses user producer interaction in technological innovation. This literature accommodates many insights about the different objectives of UPI and their underlying assumptions about the circumstances in which they are important. Most of this literature concentrates on elements of what we broadly define as UPI. For example, feedback from users to producers could involve lessons about performance characteristics of technological products [17] as well as about unexpected behavioral patterns in product usage [18]. UPI practices usually combine such elements. Moreover, coming from different theoretical traditions, there is overlap between different types of UPI. For example learning by doing underlies innofusion, insofar it applies to users as co-producers of innovation, and social learning builds on innofusion, in other words the different types are not mutually exclusive. Our endeavor is to distil a limited number of generic types of UPI. Inspired by Stewart and Williams [19] and Oudshoorn and Pinch [2, 14], we distinguish between constructing linkages, broadening, characterizing users, upstream involvement, first user enrollment, feedback, and downstream innovation.

2.1. Constructing linkages

Any UPI presupposes adequate linkages among and between users and producers. Such linkages develop by interacting and they are getting stronger when they are frequently used. *Learning by interacting* refers to a time-consuming process of *constructing linkages* through which information can pass, including a common code of information to make the transmission of messages effective [5]. It is a prerequisite when frequent interaction is required, e.g. when information and knowledge are tacit and difficult to communicate or when actors have to rely on one another's expertise [5, 20, 21].

2.2. Broadening

In early phases of technology development it is difficult to identify and characterize the range of potential users and affected actors. There might be a need for *broadening* to create awareness of possible impacts. Van Merkerk defines broadening as "widening the perspectives of actors in terms of identifying a broader set of actors and aspects" [22, p. 42]. As an important element of constructive technology assessment (CTA), broadening is a constructive intervention in an early phase of development, when technology is still sufficiently malleable to steer it in desired directions [23-25]. By broadening their perspectives, actors 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 [26]. This, for example, happens when a CTA practitioner develops scenarios of possible developments and brings together 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 [22]. According to Smits broadening significantly contributes to the success of innovation: “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” [3, p. 869].

Bijker’s [27] notion of a technological frame helps clarifying how deliberation and collaboration could eventually lead to the sharing of visions and the division of responsibilities. A technological frame emerges from and structures the interactions among actors in an innovation system. It consists of goals, key problems, problem-solving strategies, theories, tacit knowledge, users’ practices, perceived substitution function, and exemplary artefacts [28, 29]. When actors are sharing these elements, then a technological frame emerges ‘around’ an artifact. *Frame sharing* thus 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 artifact [27].

Although broadening is often associated with consensus building and frame sharing, it is important to note that the articulation of diversity and dissent can also be key outcomes. Broadening the debate about emerging technology then aims at the revelation of diversity of interests and expectations and the undoing of stable elements of existing frames in order to open up spaces for learning and probing.

2.3. Characterizing users

Marketing research is a discipline engaged with the *characterization of users* and markets. Marketing research may offer important insights for design decisions. But rather often marketing departments are institutionally divided from design departments, reflecting a linear model of innovation. In this model, product design is seen as an activity of scientists and engineers, whose products are not handed over to marketing until a prototype has been created.

The flaws of this model are twofold. First, increasingly more firms are becoming vertically integrated and improving the feedback and feedforward links between design and marketing. Innovating producers try to determine user needs and requirements in advance [30]. Second, also without involvement of marketing specialists images of users are constructed and used to inform design decisions, though perhaps in a more implicit way. The concept of *user representation* captures both these explicit and implicit modes of user characterization [31].[2] How are adequate representations of users, including their needs and capacities, constructed in design contexts? Akrich mentions six representation techniques: personal experience, experts, comparison to other products, surveys, user testing, and user feedback. The process of user representation is of interest, because it is a way for producers to deal with the unpredictability of the demand side when products are radically new and there is no established market yet. 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” [31, p. 168]. Especially when users are heterogeneous, representativeness cannot be taken for granted and there is a clear need for adequate user characterisations. Designers need to make choices that are difficult to reverse but that nevertheless determine the destinations of new product and their success or failure. The construction of specific and adequate user representations can provide an orientation for designers.

2.4. Upstream involvement

Broadening and user characterization are often acts by either producers or intermediaries like CTA practitioners in order to let various users and implicated actors enter the scope of producers. With *upstream involvement* users become active agents themselves, who participate in the process of research, design and development. Upstream involvement is a learning process, because users often do not have precise knowledge, demands, needs and requirements in advance [32-34].

Enriching is an important element of upstream involvement. Technological innovation processes are generally very complex and difficult to control, but are certainly not autonomous. Loci for influencing innovation do exist [35]. But users may not become effectively involved until users are enriched with understanding of the dynamics of technology development and their space for maneuver [22, 35]. 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” [22, p. 42].

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[2] It is important to note that Akrich’ [31] concept of user representation covers more than merely characterizing users. Her point is both socio-technical and political: designers make assumptions in the face of heterogeneous users and inscribe these assumptions in the content of the technology. Underlying values and prejudices may be reproduced when these technologies are implemented.

One of these roles is upstream *demand articulation*. Following Boon et al. demand articulation may be defined as “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” [32, p. 645]. To this definition Rip [33] adds two notes pertaining to 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 upstream developments. Secondly, he argues that the articulation of concerns has become more important in addition to the articulation of needs. Upstream involvement thus comprises both demand articulation and acceptability articulation.

From the perspective of demand and acceptability articulation, UPI would be improved when it includes a broadening exercise, aiming not only at inclusion of those targeted by innovating producers, but also of implicated actors: those who are not directly involved or targeted but who nevertheless bear consequences of technological decisions. The UPI analysis would accordingly benefit from adopting a broad definition of users.

2.5. First user enrollment

The selection and *enrollment of first users* is important for several reasons. According to the lead user argument, most potential users will not have the real-world experience needed to provide accurate data to market researchers. For innovative products, market researchers therefore focus on lead users, who are familiar with conditions that lie in the future for most others. Lead users’ perceptions and preferences can therefore serve as a need-forecasting laboratory for marketing research [12].

Another reason for strategic first user enrollment is to gain competitive advantage under increasing returns to adoption [36]. Increasing returns occur when one adoption decision leads to another, for example because uncertainty decreases. Increasing adoption depends on first users’ capacity to influence other potential users. Because potential users with similar profiles of social relations as lead users are also likely to make similar adoption decisions, it is strategically important to select representative first users [37].

In a comparative case study of road navigation technologies, Mangematin and Callon [36] make two important contributions to this argument. First, lead users who seem strategically important for the first technology are not necessarily the same as those targeted by promoters of the second technology. In one case, the technology relied on in-vehicle equipment that is provided with data via pre-existing broadcasting infrastructure. Important first users were car owners. While the system already worked well with few users, economies of scale would be beneficial. The other technology relied on an infrastructure of beacons that calculate the time a vehicle needed to travel between two beacons. Public investments in infrastructure were necessary as well as private purchases by car owners, who provide legitimacy to public investments. First users in the second case were rather municipalities of large cities and municipal fleet owners.

Their second note is that the choice of first users may influence design decisions. Because persuading first users is crucial in situations of technological competition, suppliers may need to adjust their technology in line with the specific requirements and expectations of the first users targeted.

Apparently, first user enrollment overlaps with some other types of UPI like user characterization by means of usability trials. The distinctiveness of this type of UPI is its emphasis on strategies of supplier vis-à-vis competitors. Just like technological interrelatedness and standardization, first user enrollment is of crucial importance just before market launch.

2.6. Feedback

The concept of an innovation system emphasizes that innovations do not come about in a linear way. Production and use of technological artefacts are coupled via feedforward and feedback interaction loops. The abovementioned anticipatory types of UPI are typical examples of feedforward. *Feedback* is clearly another important type of UPI.

One form of feedback is *learning by using*, focusing on technological performance characteristics. Learning by using is a success factor in the majority of incremental innovations. According to Rosenberg, learning by using “begins only after certain new products are used. […It] constitutes a feedback loop into the design aspect of new product development” [17, 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 (which could also be denoted as downstream demand articulation) can thus contribute to the optimization of performance, servicing and maintenance characteristics of capital goods [17].

Another type of feedback is about the characteristics and capacities of users. In a case study of usability trials, Woolgar [18] has shown how innovators observe users' confusions, mistakes and other responses to innovative technology in order to find ways to redirect users and teach them 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 uses. Configuring the user means "defining the identity of putative users, and setting constraints upon their likely future actions" [18, p. 59]. While this definition suggests that producers force users into a certain role, Mackay et al. [38] 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.

Learning by using and configuring the user denote two distinct forms of feedback: the first is concerned with technological characteristics, the second with user characteristics. These processes contribute to further demand articulation, but more downstream than is assumed in constructive technology assessment.

2.7. Downstream innovation

Although feedback often leads to useful improvements, users remain relatively passive in the process of innovation. Users may also be actively involved in *downstream 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* [39, 40] and *user innovation* [6, 41] are introduced. These refer to the adjustments to the technology deliberately made or initiated by users.

Innofusion is a contraction of diffusion and innovation [39]. It refers to the adaptations and improvements that users suggest or make when they implement technology into their local situation. Exploiting 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 users have diverse demands and needs, because this situation calls for customized solutions. Innofusion requires flexible, configurational technologies that offer sufficient opportunities for adaptation and customization [19, 39, 40].

User innovation refers to the recognition of design possibilities, the exchange of innovation related information and the sales of user products within user communities [6, 8, 41, 42].

That is: enthusiast and skilled users are dominant agents in all phases of the innovation process [43]. Flexible, modifiable technology is suitable for user innovation, because of the multitude of design possibilities these offer [44]. 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 [44]. Under these conditions, demanding users are forced to design their own 'prototypes'. But user innovation also occurs when industry fails to recognize a need or design possibility. In this case, however, one would expect that new manufacturers emerge or existing manufacturers try to appropriate the knowledge because of economies of scale.

After the identification of seven types of user producer interaction we now turn to the contextual conditions from which these UPI types derive relevance.

3. The context of UPI

In this research we argue that different contexts or circumstances demand different types of UPI. The current section elaborates three important variables – the type of technology, the phase of technology development and the heterogeneity of users – that together shape the context and determine to a large extent which types of UPI are relevant. An argument for distinguishing these variables can be found in an inspiring article about user involvement in ICT innovation, in which Stewart and Williams [19] distinguish between two perspectives – a design-centered perspective and a social learning perspective – and show how types of UPI are associated to either one of them.

The 'design-centered' 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 favored, once these artifacts are put in use. Improved UPI 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 centered design, constructive technology assessment and participatory decision making can contribute to this aim.

In contrast thereto the authors put another perspective in which the innovative role of users and other actors 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 (innofusion). 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 among others 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 social learning perspective is appealing when thinking of cases of flexible, customizable types of technology, like ICTs. In those cases there is considerable freedom for users to configure technologies to their personal needs and wishes. Adaptation and learning in the context of use would indeed lead to better technology. If technologies are not flexible and cannot be configured to individual needs, the design-centered perspective might suggest important lessons for user involvement. In those circumstances, concepts like upstream user characterization and involvement seem to be very useful.

This article proposes a somewhat more differentiated *typology of technologies* in order to generate additional understanding about the role of user producer interaction in technological development. The typology is based on the conception of a technology as a set of affordances and limitations that prescribes or suggests how an artefact should or could be used [45-48]. Affordances and limitations do not determine user behaviour and capacities, but one can discern degrees of coercion [2, 49]. 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 [2, 50] and such learning processes may give rise to technological adjustments [17] or induce further technological innovation [39, 41]. The point is that technologies differ in their degree to which affordances and limitations are specified, depending on the interrelatedness of system components, the level of standardization, and the stability of performance parameters [51, 52]. This degree, we argue, is crucial to understand the role of UPI in technology development.

Molina [53] has reviewed several categorizations of technologies under the headings of innovation-focused taxonomies, firm-focused concepts, and technology-focused concepts. He hints at Fleck's [51, 52] technology-focused typology as the most relevant from a UPI point of view. At the level of analysis of this study – technological artefacts – Fleck distinguishes between discrete technologies, system technologies and configurational technologies. He also distinguishes component technologies, being the elements which system and configurational technologies are made of. We concentrate on implications for UPI of these three types of technological artefacts.

Discrete technologies are self-contained products that end users can make use of in a direct and immediate way (e.g. matches or Aspirin). Design specifications and user prescriptions are relatively well defined and stable. Therefore, innovation of discrete technologies allows for a strict division of labor between R&D researchers and users. For users, it is a 'take it or leave it' adoption decision. According to Fleck [51, 52], discrete technologies do not require active user participation beyond decisions in the market place. Nevertheless, we hypothesize that decisions in the market place still assume roles for users, such as expressing the scope of demand or deciding about the circumstances in which it is appropriate to make use of the technology.

System technologies are complexes of component technologies that mutually condition and constrain each other. 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 this interrelatedness of components. Innovation in system technologies require collaboration between experts at the level of components as well as with those involved in overall system design. According to Fleck [51, 52], the role of users depends on the extent to which systems are stabilized and standardized, and the extent of customization that henceforth remains. We hypothesize that, akin to discrete technologies, a narrow extent of customization requires a lot of social learning about how to use the technology. When components are more loosely related, the extent of customization is larger, and more technological variation is to be expected at the system level. Since these variations compete for the market standard, we expect that UPI types like adequate user characterization and first user enrollment play an important role.

Configurational technologies 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. Configurational technologies lack a single standard for overall system performance. Instead, the components may be deployed in a wide range of ways in order to match externally set requirements. Thus, the main difference with system technologies is that their affordances and limitations are shaped during the implementation process instead of prior to it. According to Fleck [51, 52], UPI will mainly be oriented at the mobilization of local expertise. User participation is required as only few of the configurational possibilities are fully understood and it remains unclear how new possibilities should be configured to become what users want. Fleck emphasizes the importance of ‘learning by trying’ in these circumstances [40].

Apart from the type of technology, it is widely acknowledged that the nature of innovative activity also changes along different *phases of technology development* [54, 55] with important consequences for the types of UPI that should be employed in these different phases [19, 35]. In early phases, technology promises to bring various opportunities for innovation and it is difficult to predict which directions will become successful. In later phases, outcomes of technology development are easier to predict but more difficult to reverse, due to earlier decisions and investments [54]. Rip and Schot [35] argue that these phases can also be distinguished on the base of typical activities. In an early phase, typical activities are the identification of technological opportunities, mobilization of resources and articulation of functionality. Later on, typical activities include constructing and testing prototypes, identification of lead users, and market introduction of the technology. Finally, the emphasis shifts towards activities like standardization, exploiting economies of scale and scope, infrastructural development, and process innovation. These clusters of activities suggest a similar distribution of UPI types along phases of development, as terms like upstream, downstream and feedback already indicate. Some types of interaction are mainly relevant in early phases, while others are in later phases. UPIs are thus a subset of the clusters of innovation activities that Rip and Schot distinguish, which should be studied in relation to phases.

The concept of phases also draws attention to the evolutionary relations between Fleck’s [51, 52] types of technologies. Configurational technologies, for example, often evolve into system technologies when configurational activity becomes path-dependent, user requirements converge and system standards emerge. Even further in their stabilisation and standardisation, some generic systems may evolve into discrete technologies and eventually become constituent components of other systems and/or configurations. But there are also examples abound (e.g. in robotics) of situations in which local contingencies continue to resist standardization and systematization [56]. What is more, technologies may evolve from systemic into configurational technology over time, for example when enthusiast user communities acquire sufficient technical skills to deconstruct integrated systems or to reconfigure them into technologies that serve their own purposes, or by the introduction of standardized parts in the supply chain. The use of automobiles as a stationary power source in rural America or the invention of mountain bikes are nice examples here [8, 29].

A final concept for understanding the importance and type of UPI is the *heterogeneity of the user population*. The more heterogeneous users are, the more complicated it is to align technological opportunities to user demand. In case of discrete or system technologies such alignment might occur by closure of controversy [27], for example due to standardization or convergence of demand. Similar dynamics might also appear in the development of configurational technologies, which would then evolve into system technologies. However, if technologies are highly configurational, then heterogeneous users may also be served with differentiated products [44].

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) [40, 57]; 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) [2]; and these users may have very different capabilities and knowledge bases (depending on e.g. education, skills, experience) [31]. We use the notions of relevant user group and technological frame to define user heterogeneity [27-29]. A relevant user group is one social group among engineers, advertisers and other users groups involved in innovation. Each of these social groups shares a particular meaning of an artefact. With regard to the early development of the bicycle, for example, Pinch and Bijker [28] distinguish the relevant user group of young men from the group of women and elderly because these groups associated different meanings with the bicycle ('macho machine' versus 'unsafe machine'). We define user heterogeneity then as the existence or emergence of multiple relevant user groups. These could be end users, proxy users or intermediary users, lay users or professional users. User groups in the broad sense are relevant when they are involved or implicated 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. Bijker's [27] notion of a technological frame is introduced to emphasize that users do not attach meanings to technologies at random. Meaning attribution, and hence social group identification, takes place with reference to these more widely relevant and historically patterned technological frames.

4. *Four cases of UPI in technological innovation*

In the first part of this paper, several types of user producer interaction (UPI) are discussed and three variables, i.e. the type of technology, the phase of technology development and the heterogeneity of users, were introduced that determine the demand for types of UPI in a particular context. The second part of the paper makes three further contributions. The first is to provide empirical support for the claim that types of technology demand different types of UPI. We present different technology types in four case studies and investigate whether different UPIs indeed can be identified. The second contribution is to show how UPI affects the dynamics of innovation. The case studies identify key factors in the development of technology and highlight how particular types of UPI have contributed to these factors. The third contribution is to reflect on the co-evolution of technology type and user heterogeneity in a specific phase of technology development and the role of UPI therein. The case studies might even show how technologies sometimes evolve into another technology type.

The four case studies reflect the different types of Fleck's typology of technologies in the following way. The first, clinical anaesthesia, is a typical example of a discrete technology. The second, the refrigerator, is a system technology with early standardization and stabilization of design. The third, Video Cassette Recording (VCR), is a case of two system technologies competing for the market standard. And the fourth, the bicycle, is an example of a configurational technology that evolved into a generic system and back to configurational technology. These examples are chosen due to their eligibility to underline technology and user characteristics and are based on existing and well documented cases in innovation studies, like [8, 58-64].

Each case is introduced with some background information in order to identify key factors in the development of the technology according to the literature. Each case shows how relevant UPI types highlight certain activities and interactions and how these interactions contributed to the key events of the innovation processes, thereby influencing the dynamics of innovation. In these analyses various phases of technology development assuming different types of UPI are taken into account.

4.1. Discrete technologies: the case of clinical anaesthesia

Discrete technologies are self-contained packages, which the consumer can make use of in a direct and immediate manner without much learning or interfacing with other elements. Obvious examples are 'plug and play' mass products like matches or toothpaste. According to Fleck [51, 52], they do not require the active participation of users except their selection decision to articulate their demands to producers. We selected the case of clinical anaesthesia in nineteenth-century American surgery to elaborate on the implications for UPI. Although anaesthetic products did require interfacing with other elements, such as medical professional guidelines, such interfacing merely happened in the context of use. Therefore, the case of clinical anaesthesia, which is carefully documented by Pernick [61], is interesting for the exploration of the difficult nature of selection decisions of discrete technologies.

The two anaesthetic products used in the mid-nineteenth century were ether and chloroform. While these anaesthesia themselves were discrete technologies – the same substances were used, though in varying doses – different groups of surgeons and dentists attached diverging meanings to the new technology [61]. There were many opponents with fundamental objections, who considered anaesthesia 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, or as an unacceptable risk (some patients never woke up, wrong limbs were amputated). Pernick characterizes these early days 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. They varied doses according to presumed sensitivity of patients and the kind of surgery.[3] 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

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[3] 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 [61].

pride, and public and private channels of communication. Nevertheless, attitudes converged over time and the pragmatic approach appeared to be successful given the rapid growth of the third group compared to the other groups.

Pernick discusses a number of key factors responsible for the selective but growing use of anaesthetics [61]. 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 compromized orthodox and sectarian medicine by 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 regional and national associations.

UPIs 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. Broadening can be a *de facto* manifestation of controversy because actors actively oppose a certain development [65].

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 context. But this broadened orientation also urged for frame sharing: i.e. 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, even though some (mainly younger) surgeons were stronger included in the frame than others and surgeons differed in weighing particular aspects. But the new frame at least allowed for a reasonable debate in which ideology only played a minor role. The frame started to stabilize, when statistically sound procedures and rules started to guide decision making about the use of anaesthesia and became part of more general notions of good medical practice.

The formulation of guidelines and procedures and debates about these procedures in journals and meetings of associations were indirectly based on experiences of surgeons using the new anaesthesia. Many lessons from using were fed back via statistical analysis of medical records of hospitals. In this sense, feedback contributed to the diffusion of anaesthesia, but targeted medical guidelines rather than product improvement.

Of further interest here are the linkages through which feedback via medical records led to formulating medical guidelines. Constructing linkages 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 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 anaesthesia well illustrates how theoretical concepts like broadening and frame sharing, feedback, and linkage construction are relevant for understanding UPI about discrete technology. Moreover, these types of UPI appear to contribute importantly to the convergence of user demand. 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, and in discrete technologies in general, processes of adoption were far more crucial than for instance user involvement in investment decisions by producers. Consequently, due to this demand-side focus, UPI types like user characterization and upstream involvement, which emphasize user roles from the perspective of producers, do not appear relevant. Upstream user involvement would not have made a big difference in terms of product design. This confirms Fleck's [51, 52] assumption that users are mainly involved in later phases of discrete technology development,

4.2. System technologies with early stabilization: the case of the refrigerator

System technologies are complexes of component technologies that mutually condition and constrain each other. Examples of system technologies are mass market products like grass-mowers, 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 large market segments. After the establishment of a dominant design, innovations tend to be only incremental, because of the intertwinement of components. In this paper we distinguish between a situation in which one dominant design soon emerges and a situation in which multiple designs compete for dominance. To illustrate the types of UPI relevant in this first situation, we selected the case of the domestic refrigerator.[4]

Consisting of a large number of components, the refrigerator is an example of a system technology. Its dominant design stabilized in an early phase of development, partly because its working mechanism prescribes a particular configuration of components. A liquid, called the refrigerant, transports heat from the inside to the outside through a process of compression, cooling, expansion and evaporation. Because these components mutually require each other, most machines for domestic use were similar[5] and competition was a

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[4] In this paper we do not discuss the very first phase of mechanical refrigeration. See [55] for the transition of harvested ice to manufactured ice and the adoption of ice machines in restaurants and cruise ships.

[5] A differently assembled type is the refrigerator based on absorption instead of compression. In her study about corporate strength, Schwartz Cowan [62] describes the principle differences between a gas fired absorption refrigerator and an electrical compression refrigerator. Although absorption refrigerators were more silent and therefore perhaps more attractive, their 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.

matter of price and design style [60]. Another reason for the similarity between most early designs 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 [60]. For example, market researchers recommended pioneering manufacturer Frigidaire to "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" [60, p. 704]. 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. 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 [55, 60, 62, 64]:

- 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;
- Electricity 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.

UPIs have importantly contributed to some of these key factors and the dynamics of the refrigerator innovations. Initially, however, characterizing users was not considered the most difficult part of the innovation process. The existing iceboxes informed entrepreneurs (and investors) in an early phase 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

[60]. Manufacturers derived the expected demand for refrigerators from the growing demand for iceboxes [62].

The most prominent type of UPI was feedback. In the development phase and the first years after market introduction, most issues were technological, such as finding the best refrigerant, designing reliable components, and sealing the system against leakage [62]. Enhancing technical performance of refrigerators happened at design departments, but continued through a process of learning by using after early models had entered the market. Issues like leaking tubes, malfunctioning compressors, broken thermostats and motors, and frozen pipes only became clear as lessons learned from prolonged usage. These solutions were thus informed by feedback and learning by using. Furthermore, lessons learned about user preferences were related to size, weight, automatic control, reliability and safety. These demands were addressed in subsequent product cycles and amounted to the path-dependency of the development process and to a relatively stable design.

During the 1930s, manufacturers started to pay much more attention to the characterization of users. When most technical problems were solved, they concentrated more on design aspects of refrigerators and the tastes of users. User representation 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 [60]. 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 in [60, p713]). User characterization occurred by emphasizing the disadvantages of existing refrigerator models and was mediated by market researchers, design consultants, retailers, and others who claimed to speak for housewives in general.

Collecting feedback about behavioral aspects of refrigerator use occurred via the work of intermediary users like home economists and industrial designers. This type of UPI covers gathering information about potential mismatches between values inscribed in the technology and the behavior of users as well as suggesting solutions to better align users and technology. These solutions could involve the reconfiguration of the technology, but also the reconfiguration of users [18]. Intermediary users strongly contributed to configuring the refrigerator user. Home economists, a professional class of mainly women who informed the general public about matters of health and hygiene, were employed by refrigerator producers and visited households to promote ideas of 'scientific housekeeping' and to remind women of their responsibility for the health of the family. 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 [64]. 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. The white color of refrigerator doors, which begged for keeping clean, reflected the importance of hygiene and proper food storage. Also the size and the interior, enabling housewives to save money by buying milk, meat, and vegetables in bulk, to reduce shopping trips, and to use 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 refrigerator was thus an 'object lesson' for the working class, as it taught middle-class social norms and tastes. This 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 case of the refrigerator highlights the work of intermediaries in characterizing users and organizing feedback. Market researchers claimed to know the homogeneous, middle-class character of the refrigerator user when they recommended particular design decisions to manufacturers. Home economists collected feedback about and intervened in the behavioral aspects of refrigerator use. Their work was to configure the refrigerator user by promoting the kind of housekeeping in which the refrigerator played a central role. Accordingly, these insights illustrate how technology, users, intermediaries and cultural contexts co-evolved and came to early stabilization of the refrigerator as system technology.

4.3. System technologies in competition: the case of video cassette recording

The refrigerator is an example of a system technology with early stabilization. Technological interrelatedness of components, economies of scale and converging demands quickly contributed to the establishment of a generic identity that governed overall system design. In the case of video cassette recording (VCR), the literature rather points to competition between multiple system designs. Due to its configurational flexibility, different types 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 [59].

In this early phase, Sony seemed to be the most successful pioneer. After 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. 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, recording time, inconvenience and costs. In this context, pioneers made different decisions. Sony decided to focus on miniaturization of cassettes and JVC (and others) on increasing recording time. They were aware of the importance of one standard to enable interchangeability of cassettes. In this standardization battle, mainly between Sony's Betamax and JVC's VHS system, the latter survived and nearly all other producers would in the end adopt the VHS standard.

In the literature we found the following key factors that explain the course of events in the development of video cassette recording [58, 59, 66]:

- 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 (e.g. Matsushita) 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 and rental businesses 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 UPI 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 invested in user characterization. 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. Its main incentive was miniaturization, i.e. reducing size and weight of both machines and tapes. But by predominantly focusing on this user relevant aspect, Sony paid insufficient attention to other aspects and its first Betamax model only allowed for one hour recording time. To foster demand articulation, American television manufacturer and 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 two hours [58]. Sony had omitted to perform such user research. Also potential collaborators such as Matsushita, Hitachi, Sharp and Mitsubishi decided to wait for the VHS format with 2 hours recording time, which JVC announced a couple of months later. Together with most European and American manufacturers, including RCA, they jumped on the VHS bandwagon.

This responsiveness to user needs is one element of what Cusumano, Mylonadis and Roosenbloom [58] called the 'strategic maneuvering' of JVC and Matsushita. Considering whether to focus on one best design or on increasing production capacity to prepare for mass production, JVC and Matsushita opted for the latter. 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 showed more modesty and flexibility, because JVC needed others to be able to produce enough quantities for the different markets across the globe. JVC thus aimed at enriching others to improve the VHS standard, by providing assistance in manufacturing and marketing. “One outcome of JVC’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 [JVC] might not have pursued itself” [58, p. 16]. Their approach was to construct linkages through which important feedback was organized, in order to form alliances and increase production capacity.

Another manifestation of this strategic maneuvering was the choice of first users. The two-hour recording time allowed JVC to enroll movie rental companies in their networks. 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. The demand for MV pre-recorded VHS tapes increased relative to Beta tapes and MV expanded capacity for producing VHS tapes. In general, the emergence of a video rental business and a growing availability of movies on tape was a decisive element in the standardization battle. 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 [66]. In effect, In 1980, VHS’ share in cassette sales was estimated to be between 70% and 90% [58].

To conclude, VCR is a system technology that could be configured in a variety of ways, but stabilized in one particular way. The case shows how the very interactive approach towards partners, proxy users and first users allowed JVC and Matsushita 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 feedback and suggestions for improvement. They strongly anticipated the role of the rental business in the adoption of a standard. The most important result of this 'strategic maneuvering' was the de facto establishment of VHS as the standard for video recording [58]. User producer interactions, such as user characterization, linkage construction and first user enrollment seemed to be relevant for the stabilization of the VCR technology.

4.4. 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 UPI in configurational technologies. Due to its assembled nature, the wide availability of components, and the relative ease of reparation or modification, the bicycle is a typical example of a configurational technology [20].

Early bicycle development showed many variants (running bikes, rear driven, front driven, low-wheelers, high-wheelers, tricycles, etc.),[6] most of which failed to become a commercial success. One exception was the high-wheeled, front driven, and relatively fast 'Ordinary'. The Ordinary became a dominant design among wealthy, young and sportive riders, who used the bikes to show off in parks and race against each other. 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. For them manufacturers began producing lower bicycles, tricycles, dicycles, and 'safety ordinaries'. Until the application of air tires, different bicycles served different user

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[6] 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 [27].

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.

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 downstream processes of innofusion and user innovation typical for configurational technology [39, 56]. 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.

A number of key factors in this course of events are brought forward in the literature [8, 27]:

- 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;
- 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 gave rise to a safe and fast dominant design; an industry for mass production of bicycles and components emerged;
- Different biking cultures adapted bicycles to their own requirements.

How did UPI types contribute to these factors? In the early phase of development, until the late 1860s, most bicycles were fairly simple constructions produced by hobbyists, local blacksmiths and carriage makers. In the relative absence of upstream design, we regard this activity as downstream user innovation, because these local producers stood very close to users or were 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.

Feedback processes were an important driving force in the succession of a variant. 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’.[7] In this process of bicycle development, feedback about unanticipated aspects was an indispensible, integrated activity. 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.

The concept of first user enrollment draws attention to the focus on sportive young men by bicycle manufacturers, who organized racing contests as a way to promote their products. Racing contests targeted sportive macho men. As in Mangematin and Callon’s [36] case of road navigation, first user enrollment had implications for design. Feedback inspired modifications contributing to maneuverability and speed, such as steering mechanism and wheel diameter, which 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.

Had elderly and women been selected as first users, other kinds of demonstrations (e.g. with women in dresses riding bicycles) would have been organized and other kinds of bicycles would have been produced. This, however, did not happen until pedestrians, women, elderly and other typical non-users of the Ordinary started to articulate their concerns and worries about the increased appearance of dangerous Ordinaries in parks and streets. This broadening of the debate about what a proper bike is included aspects of comfort and safety. 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. Such unproblematic co-existence is not unusual for configurational

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[7] This short summary admittedly reintroduces an assumption of linearity that Bijker carefully circumvents in his historical account [27]. See his book for a more evolutionary account that puts failing variants at an equal footing.

technologies, which can be adapted to specific demands. In this case, however, the safety discussion raised the demand for a bicycle that would be fast, comfortable and safe for both riders and pedestrians. From a configurational technology, the bicycle started moving towards a system technology with a single dominant design. The introduction of 'high speed' air tires instead of energy consuming anti-vibration springs would eventually close the controversy and lead to a dominant design, which was both safe and fast. 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 the technology – became part of one single frame. The merger of frames 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 [27].

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 downstream innovation in later phases of bicycle development, giving rise to new industrial life cycles. 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 [8]. These bikes were subsequently produced by small specialized manufacturers, soon followed by major bike manufacturers. But downstream user innovation continued when new groups of cyclists used and themselves adapt the off-road bikes in rather unexpected circumstances. Lüthje et al. [8] 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. This possibility of user innovation shows that bikes are essentially unfinished until they are fully embedded in user practices. 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. User innovation, first user enrollment and feedback loops determined many of the characteristics of the configurations. In this case, however, the bicycle evolved from a configurational technology into a system technology after a controversy which broadened the notion of the bicycle from merely a race vehicle to also including aspects of comfort and safety. A dominant design emerged from the merger of different technological frames. But over time and with mass production of standard components, innovative groups of users started seizing new opportunities to reconfigure bicycles. Types of UPI, such as downstream user innovation and innofusion, appeared to be relevant for understanding the dynamics of individualized reconfiguration.

5. Conclusions and discussion

Innovation processes take place in the context of 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, when users are very heterogeneous, or when there are relatively many design options. User producer interaction is indispensable in these circumstances. Users have to learn how to assess the usability 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 fulfill 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 UPI serve this variety of objectives.

In the first part of this article the literature on science, technology and innovation is reviewed and seven different (though sometimes overlapping) types of UPI are identified: constructing linkages, broadening, characterizing users, upstream involvement, first user enrollment, feedback, and downstream innovation. These types of UPI assume different objectives and roles for producers and users. The relevance of these types of interaction depends on the type of technology, the phase of technology development, and the heterogeneity of the user population. We have conceptualized the material dimension of this context on the base of Fleck's typology of technologies, which distinguishes between discrete technology, system technology and configurational technology. System technology is further differentiated in systems with early standardization due to technological interrelatedness of components (alike discrete technologies) and relatively flexible systems that leave room for variations to compete for the standard (more like configurational technology). This differentiation acknowledges the gradual differences between Fleck's types of technology, which is also reflected in the possibility that one type of technology might evolve into another (and in which UPI often plays an important part). It is furthermore argued that the type of UPI demanded in a particular situation also depends on the phase of technology development and the degree of heterogeneity of users.

To illustrate the potential value of this conceptualization of UPI, four examples of innovations with varying technological and user characteristics have been explored: clinical anaesthesia, the refrigerator, video cassette recording, and the bicycle. For each example, the relevant UPI types have been discussed and it is shown how these types highlight certain activities and interactions during key events of innovation processes. These examples provide empirical support for the claim that different types of technology demand different UPI types. In a case of a discrete technology, clinical anaesthesia, notable UPIs were broadening and frame sharing, feedback, and linkage construction. These findings confirm Fleck's assumption that users are hardly involved in production processes, because discrete technologies leave not much room for customization. Observed interactions occurred among users rather than between users and producers and mainly led to social learning and frame sharing within the context of use. As a consequence, heterogeneity of the user population significantly diminished.

The case of the refrigerator, a system technology with strong interrelatedness between components, highlights UPI types like characterizing users and feedback. Intermediaries played an important role in consulting, representing and shaping users. Due to component interrelatedness and good prospects of a mass market, producer decided to serve the market with very similar models. UPI therefore concentrated on social learning about how to use the technology. Especially home reformers taught housewives about the role of the refrigerator in modern housekeeping.

Video cassette recording was selected to illustrate the relevance of types of UPI in case of competing system technologies. As expected, the focus appears to be on user characterization, linkage construction and first user enrollment. The characterization of users as movie watchers (two-hour tapes) and the enrollment of the rental business as one of the first (intermediate) users, affected both the shape of the technology and its success on the market. These UPI strategies were part of an interactive approach that enabled VHS system to become the standard system.

The bicycle, finally, is a case of configurational technology. As expected, downstream innovation and feedback were very frequent, both in very early phases of development (the first bikes were not really the result of an upstream design process) and in more mature ones. Much less expected was that a standard emerged in the meantime. Instead of customized solutions for different groups of users, a broad debate about safety in the streets took place, which led to one dominant design. The debate concerned the dangers of the high-wheeled Ordinary, the development of which largely depended on the enrollment of young sportive “macho” men as first users at the expense of demands of women and elderly. The new standard temporally transformed a configurational technology into a system technology.

Quite unexpectedly, at least from a design-centered perspective, we did not encounter an example of upstream involvement in these four cases. This might be due to the fact that upstream involvement is rather a contemporary prescriptive concept for controversial areas like nuclear, bio- and nanotechnology, than a descriptive one for cases like those we explored. Upstream involvement is promoted in the context of the Collingridge dilemma, which assumes that technology is still malleable in early phases – so that it makes sense to involve users in early decision making – but it is also hardly possible to predict the impact of such involvement. In three case studies, producers limited upstream UPI to user characterization and learned from (downstream) feedback whether they made the right design decisions or not. This The only exception is the bicycle, in which case (of configurational technology) early involvement coincided with user innovation and downstream customization. The concept of development phase hardly applied in that case.

The case studies show the relevance of different types of UPI in different contexts. They also show how UPI affects the dynamics of innovation. In the case studies we identified key factors in the development of technology and emphasized how particular types of UPI have contributed to these factors. A further contribution to understanding the co-evolution of technology, users, and cultural contexts entails the observation that the influence of UPI is not limited to the success or failure, but also to the direction of technology development.

Technologies may even 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 transformed into a system technology. Later, when users started to explore alternative uses of bicycles, demands again started to diverge and become more heterogeneous (configurational technologies). A similar 'life cycle' can be observed in many ICTs [19].

Future research might deepen the understanding of UPI in context, for example by testing whether our typology of UPI should be further aggregated or differentiated. To what extent, for example, do types of UPI still overlap or is one type of UPI embedded in another? In the literature, demand articulation is introduced to emphasize the role of users upstream the development process. The case studies, however, reveal that demand articulation is also an important element of feedback and downstream innovation.

Further research could also shed more light on how the degree of user heterogeneity is both an incentive and an outcome of UPI. For example, the homogeneity of American middle-class refrigerator users was in part the outcome of feedback about user behavior by home reformers, industrial designers and marketing specialists, who collectively engaged in the shaping of refrigerator users. In a similar vein, the broadening of the meanings of anaesthesia and bicycles contributed to the effect that frames of different (non)user groups merged into or gave rise to new frames of steadily more homogeneous user populations.

Futhermore, the case studies revealed 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 extensively in our endeavour to put UPI in context, but is highly relevant when UPI is deliberately organized in a real life context.

Finally, the classification offers an outlook on developing a 'toolbox' for organizing and managing UPI in context, but our reflections also imply that this metaphor 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, much more can be learned about the particular forms, mechanisms and conditions for *effective* UPI. In our research, 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. With that in mind, our study could support analysts, policy makers and practitioners to contextualize innovation processes and to sensitize them to relevant types of UPI in those contexts.

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