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1. Introduction

Technological paradigms are a classical concept in the literature on innovation and technological change (Dosi, 1982; Granberg and Stankiewicz, 1981; Johnston, 1972). Based on Thomas Kuhn's notion of scientific paradigms, technological paradigms describe the cyclical nature of technological change and the path dependency of innovation processes in times of incremental progress. In recent years, however, technologies are perceived to be increasingly science driven and complex in nature. Under these circumstances, Kuhnian ideas of scientific progress and knowledge production become at least problematic in describing the nature of technological progress *en bloc*. The use of 'technological paradigms' thus turned out to be less fashionable in the innovation literature, so that the concept is recently used in an ambivalent fashion: whereas some still apply a Kuhnian analogy to explain the cyclical nature of technological change (e.g. Frietsch and Grupp, 2006; Murmann and Frenken, 2005), others deny the value of Kuhnian ideas to explain regularities in innovation processes altogether (e.g. Parayil, 2003; Russell and Williams, 2002).

This paper strives to revive the idea of technological paradigms and assesses the scope of its applicability. I maintain that the idea of technological paradigms provides a sharp analytical tool to understand cognitive aspects of technological change under particular conditions. While technological paradigms cannot explain innovation processes altogether they can elucidate certain aspects of technological change. In particular, Kuhn's notion of normal progress provides important cues into how technological change is shaped by design decisions that influence the cognitive system within communities of specialists. These cues, however, have never been fully utilized in innovation research, where the emphasis was either on the Kuhnian idea of revolutions or on technology as knowledge systems – the latter frequently excluding design from the analysis. What remained widely unexplored was the parallel between Kuhnian exemplars in scientific paradigms and designs in technological paradigms. I propose here a definition of a technological paradigm that focuses on the nature of normal technological progress. The definition is built around the interplay of a dominant design and a related *epistemic style*, i.e. a particular style of producing knowledge.

I continue that this definition is particular useful for the analysis of complex systems of technology. In this context and in contrast to common wisdom, I propose that technological paradigms can hamper an innovation process as they are particular to communities of specialists. Complex systems often involve distinct paradigms that jointly shape the innovation process. This particular kind of distributedness poses peculiar challenges for the

1 This research was supported by the German Research Foundation (DFG); part of it is based on my PhD thesis at Berlin University of Technology. The paper benefited from the inputs of the participants at the Innoversity Conference in Berlin which was funded by the Volkswagen Foundation.

coordination of innovation. For closed systems of technology, a design hierarchy realizes a tight coordination of different paradigms (Clark, 1985; Rosenbloom and Christensen, 1994). However, complex systems of technology often are open systems for which such a hierarchy is absent. For such systems, technological paradigms constitute a disintegrating element in the respective innovation process. I show that for open systems of technology a loose coordination of different paradigms, that leaves these paradigms intact but enables interaction between them, is a precondition for the emergence of an innovation process.

The propositions are illustrated and explored through a case study on the development of Smart Home technologies. Smart Homes are built entities (houses, flats, apartments, etc.) in which different products and services operate together and constitute a product ecology. The Smart Home field is a particular interesting area of study because comprises a number of well evolved industries. The field's innovation process spans these industries. A specific challenge thus exists due to a multi-industry setting in the field: Industry structures are not only organized along the supply chain but different industry structures co-exist on the level of the systems' components. To explain the field's innovation process, therefore, a more graded concept is needed than technological paradigms. I propose that *thought styles* as they were defined by Ludwik Fleck in 1935 (Fleck, 1935) provide that kind of gradation. Even though very influential for him, Kuhn did not admit to what for Fleck was a most important driver of progress: the interactions between distinct thought styles.

This paper is organized as follows. Section 2 reviews the concept 'technological paradigm'. It starts with a brief introduction to the ideas of Thomas Kuhn. Subsequently, the early adoptions of Kuhn's paradigm concept to the analysis of technological change are discussed. It is shown that a crucial aspect of the Kuhnian idea – a supertheory clustering around an exemplar – was never fully exploited in the literature on technological change and innovation. A definition of technological paradigms is then introduced that elaborates on the notion of normal technological progress. Also, the scope and the limits of this definition's applicability are indicated. Section 3 presents the empirical case. First, the origins of the Smart Home field are introduced as a push from industrial markets to consumer markets. Secondly, the peculiar multi-industry setting in the field is described and two dominant strategies to cope with it are identified. Section 4 applies the definition of technological paradigms to the case and analyzes the Smart Home field's dominant modes of coordination through Kuhnian lenses. Section 5 summarizes the results and stretches out directions for further research.

2. Thomas Kuhn and His Legacy in Innovation Research

2.1 Scientific Paradigms

Thomas Kuhn's seminal work *The Structure of Scientific Revolutions* was originally published in 1962. In this book, Kuhn outlines an understanding of science that starkly differs from the logical positivism of the Vienna Circle and from the Critical Rationalism of Karl Popper. For Kuhn, science is not merely a matter of cumulativeness but rather proceeds in phases of cumulative progress (normal science) and radical shifts (scientific revolutions). The very nature of *normal science* – and thereby the very nature of most scientific activities – is articulation, not replication or falsification: Scientist attempt to further articulate the propositions accepted in their field of study to accomplish a larger number of problems solved and greater accuracy of prediction. Consequently, normal science is introduced as a process of puzzle-solving ("mopping-up") which is targeted at elaborating expected solutions to accepted problems. The accepted problems and the expected solutions to these problems are – by and large – fixed in what Kuhn calls a *paradigm* that is shared within a scientific community. Normal science as conceptualized by Kuhn does not produce much novelty. Only in rare instances, facts discovered cannot be brought into accordance with a predominant paradigm. Occasionally, such instances may lead to a paradigm shift, for which Kuhn coined the term *scientific revolution.* After a revolution has occurred, a different paradigm is accepted within the community; the *gestalt* by which scientists of this community perceive there field of study has changed.

Kuhn's book especially caused confusion about the nature of a paradigm. In particular, his plurivalent use of the term paradigm itself was criticized (see, for instance, the contributions in Lakatos and Musgrave, 1970). In the postscript to the *Scientific Revolution's* Second Edition Kuhn clarified his understanding of a paradigm and concentrates on two distinct way in which he uses the term 'paradigm': First, a paradigm marks a constellation of group commitments (rules and theories, norms and values), a kind of "supertheory" (Gutting, 1984) that guides the thinking within scientific communities. This, however, is not new as it basically reproduces the Mertonian definition of a paradigm. But there is also a second meaning of the term 'paradigm' which is an exemplary and concrete solution accepted within a community as schema for applying the rules and theories of the supertheory to problem solving. For Kuhn, this definition of a paradigm as a shared example is the actual innovation of his work (Kuhn, 1970: 187). The cognitive system of a paradigm – and that is what distinguishes Kuhn from his predecessors – crystallizes as the *gestalt* prescribed by a paradigm has been fixed in exemplary solutions. Paradigms are exemplars in the first place; these exemplars in turn embody supertheories in which accepted problems and expected solutions are fixed. For Kuhn, concrete objects – artifacts, so to speak – are at the center a scientific paradigm that outline the principles of "normal" scientific progress (Masterman, 1970). It is this interplay between concrete problem-solutions and group commitments that is the peculiarity of scientific paradigms. However, with respect to Kuhn's legacy in innovation research this is also the least understood aspect of paradigms. I turn to this issue below (2.2 & 2.3).

A third aspect has not been discussed yet. It concerns the nature of the community that shares a paradigm. Kuhn certainly touched this important sociological implication of his concept; however, he never fully elaborated on it.[2] Although he is quite optimistic that (sociological) instruments to identify scientific communities can be found (Kuhn, 1970: 176), Kuhn confines himself to fairly generic heuristic remarks about the nature of scientific communities. First, communities have to be identifiable prior to the analysis of the paradigm they share. Secondly, scientific communities are groups of specialists in a certain field of scientific study that share identical professional initiation; consequently, these groups typically refer to the same body of standard literature. Thirdly, scientific communities are entities that generate and verify scientific cognitions; scientists can typically be assumed to be members of more than one scientific community. For Kuhn, scientific communities resemble Crane (1969) later defined as invisible colleges which can be identified by mapping intellectual relations of various kinds in social networks (Verspagen and Werker, 2004). This account seems fairly sufficient to develop an agenda how to identify a scientific community; however, it misses to acknowledge how paradigms are socially generated and elaborated within communities. Kuhn delegates the latter to the social science which he apparently not regards as his affair (Kuhn, 1970: 178). This

2 Douglas (1986) as well as Harwood (1986) even go to such length that Kuhn virtually shied away from the sociological repercussions of his ideas.

weakness with regard to the structure of scientific communities also pervades Kuhn's legacy in innovation research. I turn to this issue below, too (2.2 & 2.3).

Summing up, three aspects of the Kuhnian understanding of science are important for this paper. First, paradigms are shared examples. This is the real novelty in Kuhn's work. Only once exemplars are accepted within a certain community, the implicit (and never completely unequivocal) propositions that guide puzzle-solving behavior can both: crystallize and be understood. This is what Kuhn refers to as the *priority of paradigms*: "Paradigms may be prior to, more binding, and more complete than any set of rules for research that could be unequivocally abstracted from them." (Kuhn, 1970: 46) Secondly, a paradigm sets out an array of expected solutions to accepted problems; normal science, i.e. paradigm-bound science, is widely a process of articulating further what is already known: "Mopping-up operations are what engage most scientists throughout their careers. […] normal-scientific research is directed to the articulation of those phenomena and theories that the paradigm already supplies." (Kuhn, 1970: 24) Thirdly, communities of specialists are the locus in which normal-scientific progress is shaped.

It is noteworthy that scientific revolutions are not included in this account of Kuhn's work. Clearly, scientific revolutions are a most striking aspect of Kuhn's work and this idea led too much of its popularity (Fuller, 2003). However, scientific revolutions also rank among the most problematic aspects of his work as they impose a rigid scheme on the history of science and scientific disciplines *as a whole*. This paper focuses on the idea of normal science as one force within the larger proceedings of the scientific endeavor and is thus a selective revisiting of Kuhn's ideas: It is normal science, i.e. mopping-up activities of knowledge production based on shared examples within scientific communities, which provides a valuable source for the analysis of technological change. In the following to sections I show that in the literature on technological change and innovation the Kuhnian prototype is widely used to explain radical innovations; however, it has never been fully utilized to look into how knowledge production of cumulative change, i.e. technological research, looks like and what the respective sociological implications are.

2.2 Technological Paradigms

The legacy of Kuhn's work in the literature on technological change and innovation is marked by three publications that explicitly built upon Kuhnian ideas to analyzing technological change and introduced the term 'technological paradigm'. For Johnston (1972), the periodic nature of technological change was empirically striking. To understand this, it is important to take an *internal structure of technology* into account. Assuming that this internal structure can be conceived of as a system of knowledge, a transfer of Kuhnian ideas to the analysis of technological change is most suggestive. Against this backdrop, Johnston coined the term 'technological paradigm'. For him, a technological paradigm is "a set of guiding principles generally accepted by practitioners in a particular field of technology" (Johnston, 1972: 122). Also, it comprises exemplary artifacts that prove the functioning and the success of the paradigm. Johnston, following Masterman (1970), distinguishes between paradigms as epistemological ("a guiding framework for the development of technology"), sociological (adherence to a paradigm constitutes membership to a community), and psychological ("technologists will tend to perceive the world through this framework") concept. Two aspects are remarkable of Johnston's work in the context of this paper: First, he does not consider the importance of exemplary artifacts in much detail albeit he admits their importance. For him, paradigms are accepted guiding principles (i.e. supertheories) in the first place. Therefore, Johnston misses out on fully exploring the role of artifacts within the internal structure of technology. Secondly, Johnston spent most of his subsequent discussion on the analysis of paradigm shifts. Although of great value for our understanding of technological change this focus set the stage for applying Kuhnian concepts to the analysis of technological change *as a whole*. It misses out, however, on elaborating the functioning of technological paradigms once they are established.

Granberg and Stankiewicz (1981) introduced the notion of ‘technological paradigms’ for the analysis of generic technologies. They present ‘technological paradigms’ as part of a comprehensive model of technological change that focuses on the cognitive system of technology. For Granberg and Stankiewicz, a technology can be understood in terms of the function it performs, the natural processes it exploits, and the design linking these into a functional whole. The core activity of technological research, then, is functional analysis. Understanding technological change, i.e. the evolution of a cognitive system, then depends on the understanding of functional analysis as performed in different types of technological research. In this context, a “*technological paradigm* […] denotes a set of beliefs and opinions, held in common by a sizeable collectivity of practitioners, as to how 'their' technology ought best to be developed." (Granberg and Stankiewicz, 1981: 215) A paradigm shapes the answers to questions raised by various types of functional analysis. In other words, a paradigm shapes the solutions to problems relevant with regard to a particular technology. Granberg and Stankiewicz elaborate in more detail than Johnston what kinds of activities are conducted in communities of technologist, namely technological research and functional analyses. They are very clear about the importance of the educational and professional backgrounds of practitioners as drivers of technological change. The internal structure of technology is thus not an autonomous dynamic of technology but rather a dynamic introduced by a generic style of functional analysis and particular styles of technological research. What they left widely unexplored is how these styles interact with the materially embodied part of a technology.

Dosi (1982) introduced the term ‘technological paradigm’ into the economics of technological change and innovation. Also for him, the cyclical nature of technological change was striking in which phases of incremental change alternate with radical changes. Incremental change can be conceived of as endogenous change driven by ‘technological paradigms’; consequently, he conceptualized radical changes as paradigm shifts. Dosi conceives of technology as knowledge, a transfer of Kuhnian ideas is thus most suggestive. “In broad analogy with the Kuhnian definition of a ‘scientific paradigm’, we shall define a ‘technological paradigm’ as ‘model’ or ‘pattern’ of solution of *selected* technological problems, based on *selected* principles derived from natural sciences and on *selected* material technologies.” (Dosi 1982: 152) In contrast to Johnston, however, Dosi focuses more on the technology that underlies a paradigm. For him, a paradigm relates to “a generic task to which it is applied […], to the material technology it selects […], to the physical/ chemical properties it exploits […],to the technological and economic dimensions and trade offs it focuses upon […].”[3] (Dosi, 1982: 153) A paradigm, therefore, fixes essential aspects of a technology (design principles as well as function). These fixations, in turn, induce an outlook of possible progress along certain parameters (i.e. accepted problems and expected solutions) that is shared within a community of technologists or practitioners. This outlook gives raise to technological trajectories which parallel Kuhn’s idea of normal progress.

3 Note, that the idea of selected principles derived from nature displays an understanding of the sciencie-technology link that is highly stylized. Technology quite often is simply developed without much reference to principles from natural science (Laestadius, 2005).

Although Dosi's definition of a technological paradigm itself is quite similar to the definition of Johnston, his work contains a much richer description of normal (i.e. paradigm-bound) technological progress. Dosi distinguishes between a material fraction of a technology (the exemplary artifact demonstrating the function of a paradigm) and a disembodied fraction of a technology containing expertise, experiences and practical knowledge about the state of the art of the technology. Normal technological progress is driven by a combination of these fractions. In this description of normal progress, Dosi delivers the strongest analogy with Kuhn.[4]

Especially Dosi's article spawned and influenced a number of studies in the innovation literature that more or less directly used Kuhnian ideas to analyze technological change.[5] What is missing within these studies is a thorough discussion of the functioning of technological paradigms in the light of Kuhn's original work. By applying the whole Kuhnian framework of paradigms, crises and revolutions to the process of technological change *as a whole*, much of the descriptive power that is provided with the idea of a paradigm itself and the special kind of progress it establishes remained unexplored. The following section (2.3) closes this gap and provides a detailed examination of the working of technological paradigms and on the conditions under which the concept is a viable one at all.

This discussion builds on the original work of Kuhn as well as the discussed early adaptors of his ideas to the analysis of technological change and introduces an account of *normal technological progress*. I explore what Kuhn teaches us about the functioning of a paradigm once it is established; in particular, I focus on a widely neglected parallel between Kuhn's description of scientific progress and the nature of technological change: the role of an exemplar within the cognitive structure of scientific progress. It is maintained that even though technological progress as a whole is shaped by numerous forces technology has a cognitive logic of its own (Pavitt, 2005) that is of major importance under some circumstances. I specify these circumstances and show that Kuhn's work still is most instructive if we want to understand the 'technical shaping' of technology (Vincenti, 1995). To reap the benefits of Kuhn's work for explaining certain types of technological progress, however, three aspects need further clarification: the circumstances under which certain technologies can be described as exemplars in the Kuhnian sense, the way in which these exemplars can than influence progress, and the nature and locus of the communities that shape this progress. Section 2.3 yields these clarifications where they can be deduced from Kuhn's original work and his early adaptors respectively. Consequently, the limits of Kuhnian ideas for the analysis of technological change also emerge.

2.3 Technological Paradigms Revisited: Epistemic Styles in Innovation Processes

Kuhnian paradigms are above all examples. Consequently, all early adaptors in innovation studies mention the role played by exemplary artifacts to demonstrate the functioning of a technological paradigm. However, the early adaptors also concertedly fail in fully admitting to the priority that Kuhn gave to paradigms as examples. Hence, they share an emphasis on

4 However, it also caused much criticism especially with regard to an alleged technological determinism. Van den Belt and Rip (1987), however, convincingly showed that much of this criticism is due to Dosi's lengthy and often unequivocal discussions of the implications of his ideas for economic research.

5 Kuhn's influence in the innovation literature cannot be reviewed here in detail. A comprehensive overview is provided in an earlier work of this author (Peine, 2006).

paradigms as supertheories rather than paradigms as artifacts. This misses out the opportunity to capitalize on two major virtues of Kuhn's work:

– Paradigms are exemplars. This suggests centering a conceptualization of technological paradigms on a specific artifact, i.e. a design instead of a scientific principle exploited by designs. .
– Paradigms arise at the *intersection* of three different aspects: material, cognitive, and sociological. Thus, an example accepted within a certain community gives rise to a *gestalt* by which cognitions are interpreted and directions in which progress is expected. Thus, a cognitive style crystallizes once an exemplary solution is accepted within a paradigm community.

The Kuhnian notion of scientific paradigms thus suggests taking artifacts and designs as point of origins to transfer his idea to the analysis of technological change. He also suggests a priority of artifacts and designs in understanding the nature of normal technological progress at the intersection with cognitive and sociological aspects of a community. This however, is not fully recognized in the innovation literature spawned by the early adaptors of the Kuhnian prototype. In the remainder of this section, I show that it is the interplay between a dominant design and the cognitive system of a community of practitioners that bears the greatest potential in utilizing the Kuhnian prototype to define the nature of normal technological progress. Thus, I shall propose here a definition of a technological paradigm that concentrates on the nature of normal technological progress instead of technological revolutions. The proposition is organized as follows: First, the notion of a technological paradigm is specified using three aspects of paradigms that can be derived from the Kuhnian prototype, and a definition of normal technological progress is provided. Secondly, the limits of this specification's use in the realm of innovation research are designated to delineate the applicability of the concept.

Material Aspects: Paradigms as Dominant Designs

Artifacts are the hub of a technological paradigm. This follows from what Kuhn calls the priority of paradigms: as explicit rules of a paradigm cannot unequivocally be elicited, exemplars are the repository in which the *gestalt* determined by a paradigm is stored. In the innovation literature this has most clearly be acknowledged by the notion of dominant designs that fix form and function of a technology by design rules for product and process (Baldwin and Clark, 2000; Murmann and Frenken, 2005). Thus, a paradigm in the view proposed here is not based on a shared scientific principle that is exploited by a technology but rather on a fixation of designs, i.e. functions and processes. Paralleling Kuhnian exemplars and dominant designs offers major advantages in conveying the idea of scientific paradigms to the analysis of technological change: First, dominant designs are much more concrete than scientific exemplars; the perspective presented here thus avoids some of the pitfalls associated with a technology as knowledge perspective. This, however, also implies limitations on the applicability of technological paradigms which I discuss below. It is important, though, that paradigms are most fruitful for such technologies that can be described as designs and that predominantly involve design work (cf. Stankiewicz, 2000). Secondly, the perspective indicates that products and services are not endlessly malleable, as some authors suggest (e.g. Russell and Williams, 2002). The notion of dominant designs acknowledges that the malleability of technologies is, under certain circumstances, limited due to fixations and choices made on the supply side. Again, this imposes certain limits to the scope of technological paradigms which are discussed below.

Cognitive Aspects: Paradigms as Epistemic Styles

Dominant designs influence the nature of normal technological progress. To understand this relation, one has to consider how dominant designs affect cognitive systems of technology. Such systems are a second aspect of a technological paradigm and they resemble what Kuhn called the disciplinary matrix: It is a certain cognitive style, a schema or *gestalt* by which the world is interpreted in the process of knowledge production within a certain community. I shall call this aspect of a paradigm an *epistemic style*[6] and use this term to denote a particular style of doing technological research as part of the cognitive system involved with a technology. It is thus a central proposition of this paper that technological paradigms once established give way to a homogenization of technological research that is done within a community of practitioners. A dominant design influences normal progress as it crystallizes a dominant style of knowledge production as part of a paradigm. Following Kuhn, a homogenization of research within a paradigm is never complete but allows for a commensurability of world views and thereby for an accumulation of knowledge within a community. The very possibility of normal technological progress thus depends – and this is what Kuhn teaches us – on a fixation of a dominant design that gives way to a dominant epistemic style. Such styles, in turn, delineate the expected trajectories of normal progress.

I use the term epistemic style here to denominate the cross-section of an engineering research style and a design to which it is applied: the idea of a paradigm as an epistemic style refers to technological research as part of the cognitive system of a technology and it refers to the accepted problems and solutions (the Dosian outlook, so to speak) concerning the further development of a technology. An epistemic style, therefore, comprises a dominant engineering style (note the singular) and it comprises the *gestalt* (which in turn comprises function, meaning, and future outlook) by which a dominant design is perceived through the lenses of this engineering knowledge. Normal technological progress thus arises as an epistemic style emerges after the fixation of a dominant design.

Sociological Aspects: Paradigms as Communities of Practitioners

Sociological aspects are probably the least understood aspect of scientific paradigms in general. It was shown above that this partly due to Kuhn's reluctance to elaborate on the structure of scientific communities. Consequently, sociological aspects of technological paradigms are only little understood as well (cf. Tuomi, 2002: 122-137). The early adaptors followed Kuhn in maintaining that it is a community of specialists that shares a paradigm. They remained widely silent, however, on questions such as where communities can be located and how they can be isolated. Against the backdrop of the above discussion of material and cognitive aspects of a paradigm, we can now specify that paradigms are shared within a community of specialists that is concerned with the knowledge production regarding a particular dominant design. This in turn produces an important insight: paradigms are confined by the boundaries of the respective *industrial sector* in which the dominant design's rules have been agreed upon. Within an industrial sector, the community is relevant that produces knowledge with regard to the dominant design concerned. It is noteworthy that the relation between industrial sectors and paradigms is unidirectional: Within an industrial sector numerous paradigms may exist; however, a paradigm can be located within one particular industrial sector. It follows from Kuhn's the assumption work

6 I use the term epistemic style in the tradition of Weingart (1995), Bromme (2000), and Bruun and Toppinen (2004) to refer to more or less stable patterns of thinking and acting.

that for each dominant design within a sector one community can be identified that is relatively homogeneous with regard to the epistemic style it pursues.

These are heavily loaded assumptions as they neglect the many differences within industrial sectors. However, numerous studies could show that these assumptions are justified under particular circumstances. For instance, Utterback and Suarez (1993) showed that the emergence of a dominant design leads to industry consolidation on various parameters. DiMaggio and Powell (1983) demonstrated that within organizational fields (by and large similar to industrial sectors) normative isomorphism leads to at least similarity of orientation and disposition of individuals. This is true for engineering styles in particular (Heidenreich, 2003). Brown and Duguid (1991) revealed that informal know-how trading between specialists is an important force within industries leading to communities that span organizational boundaries. All in all, these studies suggest that the Kuhnian assumption of commensurable styles of knowledge production within communities can justly be transferred to communities of specialists within industrial sectors. It is thus maintained here that within industrial sectors communities if specialists can be identified that share an epistemic style with regard to a particular dominant design. These communities are the locus of technological paradigms and equal scientific communities as introduced by Kuhn.

Discriminatory Power and Limits of Applicability

Technological paradigms as defined here point our attention to a homogeneity of epistemic styles within technological communities. Normal technological progress – and this is what directly follows from Kuhn – depends on this homogeneity which allows for cumulative progress. A technological paradigm is established once social closure occurs upon a dominant design (form and function, process and product) that gives way to a dominant style of technological research and an outlook as to which trajectory the development of the respective dominant design will follow. Normal technological progress is thus a concept relating to well elaborated designs and describes how knowledge producing activities that are closely related to these designs shape (not: determine) trajectories of further progress.

Technological paradigms are described here as an analytical tool that offers significant discriminatory power for the analysis of normal technological progress. Paradigms under certain circumstances condition a particular form of progress that is driven by an internal structure of particular designs. This, however, must not be confused with an automatism realizing a predetermined program implicit to such a design; rather, it points to a type of closed cognitive system in which specialists dominate the further development of form and function of a design. The cognitive system of technological research, however, is never the only force shaping technological change. But the very assumption following from the Kuhnian notion of paradigms is that under some circumstances designs and the related technological research is a good proxy to understand particular innovation processes. Again, it must be emphasized that the value of technological paradigms lies not so much in understanding technological discontinuities but rather in understanding the very nature of normal technological progress.

Technological paradigms are specified here as being confined to industrial sectors. This means that they are embedded in a wider pattern of market structures, a knowledge base, and an appropriability regime (Malerba, 2004; Pavitt, 1984). However, technological paradigms highlight the meaning of communities of specialists within industrial sectors. It is maintained here that industrial sectors can be distinguished by predominant epistemic styles, more so if industry evolution is already advanced (Utterback and Suarez, 1993).

Then, industrial sectors select upon the styles of technological research they engage in according to past fixations of dominant designs. Advanced industrial sectors can thus be regarded as relatively homogeneous with regard to technological research. Sectors prefer engineers with a certain kind of training and by their involvement with certain technologies and markets ensure isomorphism of technological practices within the sector.

Technological paradigms are introduced here as a delineating force in innovation processes, i.e. as a force delineating industrial sectors. I maintain that technological paradigms might also hamper innovation processes. Whereas the concept is commonly used to explain coordinated activities in innovation processes to exploit a certain technology, the perspective introduced here thus asks for the reverse: How can innovation processes be coordinated that involve different yet clearly distinguishable (as compared to competing) paradigms? This is a question particularly relevant for the analysis of systemic technologies for which paradigms can be identified on different levels (Christensen and Rosenbloom, 1995). If these levels are not embedded within the same industrial sector, paradigms might give reason for severe problems in coordinating innovation processes. The following case study on Smart Home technologies shows that this complex technological field is troubled exactly by a variety of paradigms from which meaningful applications have to be defined. Looking at this field through the lenses of Kuhnian paradigms highlights aspects that cannot be understood based on our conventional wisdom of industrial sectors. Before turning to the empirical case, however, two limitations to the applicability of technological paradigms as conceptualized here are discussed.

First, the social closure upon a dominant design is a necessity. In particular, this means that the view proposed here is one focusing on the supply side of technology and that user innovations are blinded out. However, this is central to the idea of a dominant design: once established it causes a stabilization of a design space so that external forces upon the design rules decrease to a negligible level. Normal technological progress thus presupposes a situation in which the producers of a technology posses a significant amount of power over the identity of the technology. The applicability of the concept of technological paradigms thus strongly depends on a careful consideration of whether or not knowledge from and about users actually influences innovation processes. Only if this influence can justly be neglected, technological paradigms are a valuable tool. In this context, it is noteworthy that the actual influence of users in innovation process is a variable that is strongly contingent with the particular technology under investigation (Baldwin et al., 2006; Miles et al., 1992; Woolgar, 1991).

Secondly, technological paradigms can only be used to describe certain kinds of technologies. This is due to the homogeneity of epistemic styles that is required by the Kuhnian prototype. The concept of technological paradigms, therefore, is only suitable for such technologies that have a fairly simple cognitive base, i.e. a cognitive base which is not science driven. In particular, it must be possible to subsume the involved styles of technological research under one epistemic style. All in all, technological paradigms apply to relatively simple technologies, i.e. technologies for which design rules can unequivocally be describes, and for which function and meaning provides only little space for interpretation. Whether or not these simplifications are justified depends on the empirical case and the kind of research that is to be pursued. In every case, however, these aspects have to be carefully considered in order to not get misled by the very idea of technological paradigms. The concept itself is blind to fine-grained varieties in design rules and builds upon fixed aspects such as function, form and meaning. Where this proxy can justly be assumed, technological paradigms provide a sharp heuristic tool in thinking about normal technological progress.

3. Smart Home Technologies

In this section, I present the results from a case study about Smart Home technologies. The general idea behind Smart Homes is the use of ICT (Information and Communication Technologies) in the home to facilitate the interoperability of household products and services within a built entity. This idea has been discussed since the early 1980s and currently experiences a new wave of major interest from industry due to the increasing pervasiveness of ICT in the home and everyday live (The Economist, 2005). Hitherto, however, the state of the technological field is still characterized by immaturity in terms of market and industry structures, the stakeholder setting involved, the viability of business models and applications, and – last but not least – the systems to be designed.

Immaturity makes a field of technology a challenging object for research. In particular, immature fields of technology provide a snapshot into the formation of markets and industry constellations that is not biased by hindsight. At the same time, the generalizability of results remains a point for consideration. Consequently, the case presented here is widely exploratory and illustrative in nature (cf. Mitchell, 1983; Yin, 1994). In the analysis, I only partially present new empirical evidence. More often, secondary sources were revisited, such as important studies about Smart Homes (mainly in Germany and Great Britain), relevant technical journals in the field, and pertinent internet sources. Part of the analysis is based on my involvement with a major research group on assistive technologies in Germany (funded by the German Research Foundation) that entailed numerous in-depth talks with practitioners and researchers in the field.

The study provides an overview of phases in the development of Smart Home technologies. These phases are conceptualized as *ideal types* (Weber, 1922) to explore dominant strategies to cope with certain challenges in the field. Consequently, the dominant modes of coordination introduced below present central characteristics in the field in certain periods; they do not, however, take into account all characteristics, nor do they provide a full-blown account of the history of Smart Homes.[7] Acuminating the historical developments in the field in this way allows highlighting important peculiarities of the field in different times and comparing them from the theoretical perspective introduced above.

The concept *field* deserves further explanation. I use the term to denote a particular field of technology and borrow from DiMaggio & Powell that introduced an organizational field as “those organizations that, in the aggregate, constitute a recognized area of institutional life: key suppliers, resource and product consumers, regulatory agencies, and other organizations that produce similar services or products." (DiMaggio and Powell, 1983: 148) My origin, however, is not an area of institutional life but rather an area of technology: The field of Smart Homes contains organizations that are recognized to contribute to the development of what is below described as Smart Home technologies. Following DiMaggio & Powell, the virtue of this approach is that it includes the totality of relevant actors that must be identified by empirical investigation. This broad scope allows for a discussion of *one* field, i.e. the field of Smart Home technologies, and distinguishing it from more detailed levels of aggregation such as industries, communities, projects, or single organizations. It should not be overlooked, though, that the totality of relevant actors naturally changed over time; however, the reference to Smart Home technologies remained the element of continuity that separates this particular field from others.

7 For this purpose, excellent overviews can be found in Gann et al. (1999) and Aldrich (2003).

3.1 The general idea of 'Smart Homes' and industry setting

The idea of 'smartness' in the built environment can be traced back to the 1970s when first attempts were made to control the functions provided by a building (Atkin, 1988). For office buildings it was recognized that controlling and monitoring lights, heating, electricity, key systems, shutters, etc. would provide a cutting edge to facility managers. To realize the cutting edge, functions supplied by a building were made accessible by means of a bus system and a central control unit (normally a computer). The term *building automation* was coined in this context to describe that previously independent components of a building could be linked in a network. Building automation clearly distinguishes between the building and its 'content'; only those functions are linked to the network that are provided by the building. For office buildings, this allowed separating building functions from the daily activities of tenants. The value of this separation can sharply be defined in terms of outsourcing facility management services. Consequently, integrated solutions for automated office buildings were firmly established by the early 1980s (Travi, 2001).

For the term Smart Home to be coined, however, two developments had yet to take place. First, the early 1980s were marked by attempts to transfer the idea of building automation to the home ("home automation"). The Smart Home idea originated from this *technology push* that was driven by the desire to exploit a proven idea on consumer markets (Barlow and Gann, 1998; Miles et al., 1992). However, the value of home automation was less clear than for the automation of office buildings (What is facility management at home? Who would be willing to outsource facility management for a home (and pay for it!)?). Secondly, improvements in ICT brought into sight the possibility to link various products in the house into a network. These developments blurred the distinction between the building and its content and by the end of the 1980s the quest for home automation was expanded to include all products (and services) in the home (Aldrich, 2003). The term 'Smart Home' was introduced to describe the linking of all products and services within a house, flat, or apartment by means of a central bus system.

All of us have basic ideas of the products and services that populate our homes; few of us, however, will have experienced how it is to actually live in a Smart Home (although the number of prototype houses that regularly raffle short-term stays is increasing). From a technological point of view, the basic idea is straightforward: Whereas in conventional homes each actuator is controlled by one sensor, in a Smart Home each actuator can be controlled by each sensor. In conventional homes the washing machine has a switch, each light has a switch, the stereo has switch, and so forth. In a Smart Home all these devices can be controlled by a central unit, e.g. a PDA, a computer, or a fixed control panel. For this purpose, a bus system is needed that mutually links the devices and the control unit, and micro system technology ('computer chips') is required that facilitates the communication between devices, the bus system and the control unit.

Smart Homes can vary on three aspects: the topology, the transmission media, and the protocol. The *topology* determines how the components in a Smart Home are arranged. In particular, the topology of a Smart Home can be central or decentral. In a central topology, all components are connected to the control unit ("hub and spokes arrangement"). In a decentral topology, the components and the central control unit are mutually linked ("peer-to-peer", each component can independently elicit the state of the whole system). Usually, decentral arrangements are more flexible, more stable, and more open to ex-post alterations of the system. The *transmission media* deployed in a Smart Home settles other important parameters, such as the speed and capacity of transmissions, the interference, and the feasibility of setup changes. Examples for transmission media are twisted pair copper lines, coaxial cables, fiber optic channels, the power-line, and various wireless media. All these media provide specific virtues and vices; a proper selection of transmission media, therefore, is of great importance for the functioning of a specific Smart Home. Finally, a *protocol* has to facilitate the communication between the components within a Smart Home. Such a protocol defines the language, so to speak, that is used to make the components interoperable.

This brief technological description of the general idea of a Smart Home[8] reveals a significant complexity in terms of industries involved. In particular, three technological areas come together in the Smart Home field that in turn comprise different industrial sectors and knowledge bases: home automation, household technologies, and the ICT infrastructure facilitating home networks. First, home automation concerns the construction sector which is itself a highly peculiar industry. Supply chains and markets are relatively loosely defined as built entities are more or less unique products (Gann, 2000). Consequently, system integration in the construction industry is a highly dispersed and project based activity (Bergly, 2001). Defining viable business models is a challenging task as the definition of value is often ambiguous (Brady et al., 2005; Winch, 1998). This is even more significant when private homes are concerned. Hence, the construction sector in its projects heavily draws upon the knowledge base of engineering principles (Flanagan, 2001; Gann and Whyte, 2003). This indicates that the construction sector is relatively homogeneous in terms of its underlying cognitive system which is strongly influenced by engineering principles and design.

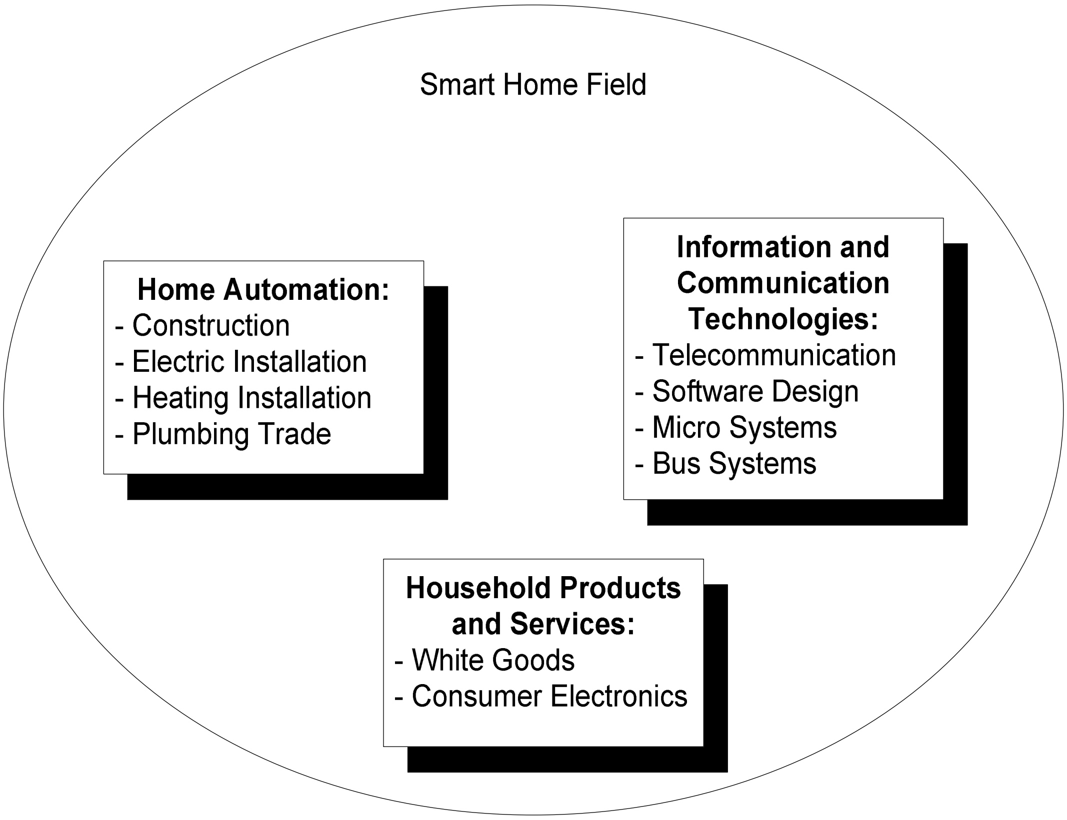
Secondly, the complete set of household products and services is comprised within the general idea of Smart Homes. A whole range of industries becomes relevant, most prominently white goods and consumer electronics. These sectors all have peculiarities in their own right. White goods, for instance, can be considered as a classical low-tech field, i.e. they are usually embedded in relatively stable market structure with low competition, and they are not science driven (Bender, 2005). Consumer electronics, in contrast, are embedded in highly dynamic markets with high competition; they are science-driven. Both areas look back on long traditions which make trajectories of development fairly stable in terms of the meaning attached to particular products. Aldrich (2003) points out that for white goods and for consumer electronics, the underlying technologies are relatively homogeneous and identifies mechanical/ electrical engineering and electronics/ computer science as the dominant cognitive systems. Finally, it is important to notice that household products and service in contrast to the construction sector can well be described in terms of manufacturing production systems.

Thirdly, ICT of various kinds are involved as the backbone of a home network. For the original Smart Home idea, this concerns the transmission media for the bus system as well as micro system technology that links various devices to the bus. However, recent developments widened this range especially since the internet is increasingly seen to be the ideal backbone within home networks and since wireless communication and the linking to external networks gained major attention (see below). Again, numerous sectors are concerned comprising, among others, micro systems technology, mobile communication,

8 It cannot be overemphasized here that the technological description refers to a general idea only, and especially to the general idea that was debated in the early 1990s when there was much technological enthusiasm about bringing ICT of various kinds into the home. Much of this enthusiasm was since displaced by more earthed debates about what kind of applications can be established on markets. Schematic as it is, however, the description provided here establishes the basic technological ideas and concepts that molded the technological field from its very origins.

and software design. With regard to innovation, this is probably the most dynamic aspect as blending ICT into homes is the core principle of Smart Homes. Figure 1 illustrates the industry setting involved in the development of Smart Homes.

Figure 1: Technological Areas and Industrial Sectors in the Smart Home Field



It is essential do distinguish between the three areas of industrial sectors because they fulfill different functions within a Smart Home. First, home automation and the construction industry concern the general structure of a Smart Home in which 'smartness' has to be embedded. This constitutes a fundamental parameter of Smart Home design. For instance, it has important consequences whether a home is designed from the scratch or 'smartness', i.e. interoperability based on ICT, is to be brought into existing homes. Secondly, white goods and consumer electronics constitute the range of products in a home that is – at least potentially – part of the home network. The selection of devices that is to be integrated and the definition how the devices are integrated are important design parameters that determine which functions can actually be provided by a Smart Home. Finally, ICT provide the backbone with which 'smartness' is realized. The selection of appropriate media and protocols is another important parameter that determines how well certain applications can be provided. Summing up, the overall relations between the three areas can be described as follows: Smart Homes are built entities in which different functions provided by the entity and/or the range of products and services in the entity are made interoperable by means of ICT.

3.2 Distributedness and modes of coordination

From the perspective of innovation research the distributedness of the innovation process in the Smart Home field is most interesting. The field comprises a variety of industrial sectors. This has hitherto impeded the diffusion of Smart Home technologies. This impediment evoked different strategies to cope with it over time. Especially, two dominating modes of coordination can consecutively be identified in the field. First, the 1990s were marked by a battle for dominance that can be understood as an attempt to establish a dominant and comprehensive standard for the design of Smart Homes. Secondly, the current state of affaires is characterized by efforts to more openly link the activities of the different industries involved. Both strategies are now discussed.

Battles for technological dominance: tight coordination

The 1990s were marked by a first wave of intensive interest in the establishment of Smart Homes on commercial markets. These early discussions were essentially molded by the attempt to establish a common standard on which different devices and functions could be linked within a home network. The challenge was perceived to be a preferably complete linking of all devices and functions in the home (Allen et al., 1999). This heavily influenced the debates in the 1990s: the key to the diffusion of Smart Home technologies was seen in a technological solution to compatibility problems. Consequently, the preferences and objectives of the important actors from the supply side were mainly focused on the development of an overall technological solution for a complete Smart Home (Barlow and Gann, 1998). Therefore, the respective strategies in the field to establish a market for Smart Homes resembled what Suarez describes as a 'battle for dominance': "[…] different technological trajectories or designs, sponsored by different actors, compete for dominance through a process where economic, technological, and socio-political factors are intertwined" (Suarez, 2004: 275). For Smart Homes, these different trajectories or designs were represented by different standards that in turn were represented by influential actors in the field.

The Smart Home standards that were propagated in the 1990s were more than communication protocols. They included a comprehensive set of design parameters that were fixed under the respective standards. For instance, whether or not a standard was open for different transmission media determined the range of devices that could be linked to a particular network; whether or not a standard allows for plug-and-play determines the flexibility of a system and the degree to which a prospective user is dependent on professional support to install or reinstall his system. On top of that, each standard had different consequences for the distribution of profits among the actors involved. For instance, attaching the IT component to the bus system rather than to the devices linked under the bus system would gain more profits to the suppliers of the network infrastructure.

In the 1990s, 10 important standards were introduced in the USA, in Europe, and in Japan. Each of these standards implied very different visions of what a Smart Home should be. These standards have extensively been discussed elsewhere (e.g. Glatzer et al., 1998). However, one particular aspect is most striking: the proposed Smart Home standards constituted technological solutions to a complete Smart Home that were largely developed without taking the wider socio-economic context into account (Barlow and Gann, 1998). Just after the fact, i.e. after the solution had been designed on the supply side, these solutions 'battled' for dominance as they were to be re-embedded into their socio-economic context ('de-contextualization', Heimer, 1995). This marks a particular strategy to resolve the problems associated with multi-industry involvement, a strategy that was build around the idea that Smart Homes can be treated as integrated systems that can be pushed to not yet existent markets once a design for the system is established. In the field different actors 'battled' for dominance with particular designs for such an integrated solution. The dominant strategy to cope with the multi-industry involvement was one that assumed that business models for integrated solutions (cf. Brady et al., 2005) would also be appropriate for Smart Home technologies.

The respective *mode of coordination* was thus a tight linking of different industries under a comprehensive design standard. However, this was misconceived as Smart Homes are not integrated systems. Rather, they have to be conceived of as open systems, that is: the basic design of a specific Smart Home is regularly fixed only in the light of a particular application. Moreover, Smart Homes considerably change over time as functions can be added or withdrawn. Consequently, the establishment of a comprehensive standard for a Smart Home did not succeed. By the end of the 1990s none of the Smart Home standards that competed in that battle prevailed. Most interestingly, however, this did not cause a halt in attempting to exploit the potential of home networks. Rather, the perception became accepted in the field that no single standard would be the solution but that the openness to particular applications is a key factor. The failing of the technology push strategy led to the conviction that the key to Smart Home markets has to be sought in considering the specificities of everyday live (Barlow and Venables, 2003; Travi, 2001). By the turn of the century, a third peculiarity of 'homes' as contrasted to office buildings was thus recognized: it is the routines and practices of everyday live that have to be regarded as the knowledge base from added value for the interoperability of household products can be derived. This caused the dominant mode of coordination in the field to change.

Open standards and the definition of applications: loose coordination

The current state of affaires in the field of Smart Homes is characterized by a number of changes as compared with the standardization debates in the 1990s. First, this concerns important technological developments of mobile communication and the internet. Due to the prevalent meaning of mobile communication and the internet in everyday life, home networks are no longer confined to the inside but are increasingly expected to facilitate communication with outside networks, as well. For instance, cars can be connected to a home network and thus function as an extension of that network, home devices can remotely be controlled with a mobile phone, or the home network can serve as the gateway to larger service systems such as the health care system (e.g. biomonitoring, assisted living, tele-medicine). In this connection, new communication standards such as Bluetooth, Zigbee, or the internet protocol TCP/IP gained importance for connecting devices at home. The manifoldness of standards became even more complex.

These changes on the technological level are accompanied by and intermingled with changes of the innovation process. Most importantly, the dominant strategy in the field to resolve the impediments posed by the multi industry setting changed. The insight became accepted that design standardization might not be the key to the diffusion of Smart Home technologies. Rather, open standards, the level of middleware, or switches that can mediate between different communication protocols are seen as important facilitators for the integration of ICT and the home. For example, the important consortia in the field (such as the Zigbee alliance, the OSGi alliance or the Digital Living Network Alliance initiated by Microsoft) place emphasis on open standard platforms that can integrate a broad range of different devices. The current situation addresses the looseness of components within the system Smart Home. A home network is perceived to be a more or less flexible configuration of products and services (ii) that can successively be installed in existing buildings, (ii) that can be altered according to changing needs and preferences of users, and (iii) that can integrate novel technologies and formats. The term plug-and-play is only one facet of these discussions that summarizes the need for flexibility and ease as it is perceived to be a key factor in the field.

The focus thus shifted to the ecology of products and services that operate in a home and that might provide additional value when made interoperable. In other words, the focus shifted towards the household as an environment that becomes 'smart' as ICT successively pervades into it. The virtue of 'smartness' is attached to the configuration of devices and artifacts operating within the built entity (Mattern, 2003) that is embedded in a particular setting of everyday practices and routines (Hughes et al., 2000). Such a configuration is 'smart' when it provides an additional value against the backdrop of everyday practices and routines in which it is embedded – not: just because it works.

This involves a particular kind of directedness of the innovation process that targets at bringing technological solutions closer to the social setting in private homes. A number of possible directions have been discussed in recent studies on Smart Home technologies. For instance, Tolmie et al. (2003) show that one possible direction of progress is technology becoming increasingly unremarkable; 'smartness' in this perspective is defined as a quality to merge with the background of homes. Another line of research concerns 'assisted living', i.e. the use of ICT in private homes of elderly people to prolong their independence at home (Cheverst et al., 2003; Curry et al., 2002) and facilitate access to remote health care services (Barlow et al., 2006). A more ambiguous field of possible application currently gains major attention: The convergence of different forms and formats of consumer electronics and communication technologies is expected to provide increased access and better organization of different kind of media (Wybranietz, 2003).

The black-box of 'de-contextualization' thus opened to the distinctiveness of private homes as opposed to office buildings. In particular, partial solutions came into sight that introduce 'smartness' into existent product ecologies as a key element towards the diffusion of Smart Home technologies. Whereas the common wisdom about standardization suggests that a failure in agreeing upon a standard of some sort would lead to a non-evolution of a technological field (Shibata et al., 2005), the case of Smart Home technologies teaches us something else. As the battle for dominance in the 1990s failed, the technological solution faded into the background and *applications* moved to the foreground of discussions. Standardization is no longer perceived to be a means of fostering the breakthrough of a dominant architecture for a Smart Home but rather it is perceived to be a platform that facilitates interoperability. Thus, interoperability remained the core of the technology in the field; yet, another dimension came into sight: making products and services at home interoperable has to provide additional value to prospective users. Such an additional value, in turn, has to be elicited from everyday practices and routines.

Smart Homes emerge at the cross-section of different knowledge bases and industrial sectors; they are product ecologies that provide additional value given a certain setting of everyday practices and routines. This is a remarkable shift away from perceiving them as integrated systems for which design parameters can be fixed under a comprehensive standard, i.e. a dominant design. This affects systems integration that can no longer be realized on the level of a technological solution but has to be realized on the level of specific applications. The dominant strategy in the field to cope with the multi-industry setting changed (and still is changing) accordingly. Knowledge about everyday practices and routines, as well as methods to elicit such knowledge, became an important informant of the innovation process. The dominant *mode of coordination* thus shifted towards a loose linking of different industries which retains openness towards the contingencies of private homes.

4. Discussion of Empirical Results and Theoretical Claims

In this section, I discuss the empirical results and show that technological paradigms are a particular useful concept to understand the peculiarities of the Smart Home field. However, they are particular useful in a way that is markedly different from the common perspective which highlights the coordinating effects of technological paradigms. I proceed as follows: First, I show that technological paradigms can well describe the different industrial sectors involved in the field of Smart Home technologies. Then, I explore the two modes of coordination successively prevalent in the field. I show that paradigms guide the innovation processes on the level of components; they do not, however, guide the field's overall innovation process. The latter is rather hampered by the existence of paradigms on the components' level.

4.1 The smart home field and technological paradigms

The innovation process in the Smart Home field is characterized by the different industries involved which can clearly be delineated in terms of well-evolved market and industry structures. The innovation process in the Smart Home field is thus actually a linking of hitherto independent innovation processes on the level of the respective industries. As industry evolution has already gone a long way in these industries, closure upon dominant designs can be assumed, at least to some degree. In other words: *The Smart Home field can be described in terms of technological paradigms that guide the innovation processes on the level of the industries involved.* That is: each industry can fruitfully be described as a fixation of material (dominant design), cognitive (an epistemic style), and sociological (a community sharing an epistemic style with respect to a certain dominant design) aspects. This assumption needs further explanation for each of the technological areas introduced in 3.1:[9]

- For the case of household products this is relatively straightforward as they almost constitute a classic case of stand-alone products as described by Dosi (1997). Especially, they have well-defined identities and meanings, i.e. the design rules for products and processes are well elaborated and the form and function of artifacts are comparatively fixed. Moreover, the cognitive base of household products can be regarded as relatively stable as innovations are not science driven. Also, the importance of user innovations can be expected to be relatively low; sophisticated methods of eliciting user preferences only recently gained attention (Rosenthal and Capper, 2006).
- The building industry is more problematic because of the peculiarities described above. However, the knowledge base of the building industry is relatively stable in terms of the

9 On a general level, the assumption is supported by the fact that most industries involved are not science-driven; they are, so to speak, low-tech and thus prone to an analysis through the lenses of paradigms. This is a particular important distinction: Whereas the whole field clearly is science-driven as it concerns the pervasion of high-end ICT into product ecologies of private homes, the actual components display relatively stable innovation processes.

underlying cognitive base, as Flanagan (2001) and Barlow and Gann (1998) intimate. And: whereas the process of building homes is widely project based, the basic idea of a house – at least to the extent important for the analytical points maintained here – is extraordinarily fixed in terms of design rules (Winch, 1998). Furthermore, the building sector is embedded in a relatively stable set of actors, which presupposes that a high degree of social closure has occurred (Utterback and Suarez, 1993).

– ICT is most problematic as it is a highly dynamic and science driven area of technology. However, a differentiation applies: ICT is important in the Smart Home field because it provides a home network's infrastructure. The question whether or not this infrastructure can be described in paradigms in not of utmost importance in relation to the claims of this study. ICT infrastructure is an important part of the innovation process in the Smart Home field; however, it is a facilitator rather than a provider of functionality itself. Where it provides functionality, stable industry structures already evolved ("brown goods").

Describing the innovation process in the Smart Home field in terms of the different technological paradigms involved directs our attention to knowledge production. The field's innovation process is influenced by a number of distinct communities of specialists each of which shares a distinct epistemic style shaped by professional training and the involvement with a particular design. On the level of Smart Home components, knowledge production proceeds as paradigm-bound normal progress. The innovation process of the Smart Home *field*, i.e. knowledge production with regard to interoperable product ecologies in private homes, in contrast, interlinks these separate trajectories of knowledge production. In addition to the conventional understanding of technological paradigms as enabling innovation processes, the case analysis here unmasks a different quality: technological paradigms bound innovation processes within industries, so that multi-industry settings are problematic due to the incommensurability of paradigms.

What do we gain from looking at the Smart Home field from this particular perspective? On a general level, a tension is accentuated that exists between the evolved nature of the industrial sectors concerned, and the ambitious attempts to design interoperable high-end system solutions that link products of these sectors. Using paradigms as a point of origin brings knowledge production and how it proceeds within communities of specialists into sight. On a particular level, the problem of system integration is thus specified as a problem of coordinating distinct technological paradigms in innovation processes. The case analysis showed that incommensurability between paradigms is not as complete as theory would suggest. This, in turn, makes it possible to identify mechanisms that account for a coupling of technological paradigms in innovation processes. More specifically, previously underrated aspects of the different coordination modes as introduced in 3.2 can be accented.

It is noteworthy that the focus on paradigms excludes other aspects from the analysis. Technological paradigms bring a specific blend of material, cognitive, and sociological aspects into consideration. In the connection of multi-industry settings the distinctness of epistemic styles in innovation processes is highlighted as a particular challenge. The perspective taken here stresses the importance of specialist's communities in the process of normal technological progress, and therefore underpins the sociological consequence that arise as such communities have to interact in innovation processes. This is clearly not the whole story but, as I believe, in the case of the Smart Home field a particular rewarding part of the story. The conclusions drawn in the remainder of this article may function as a touchstone of this appraisal.

4.2 Tight coordination: a smart home paradigm?

In Section 3, two different modes of coordination were introduced for the innovation process in the Smart Home field; these modes of coordination were described as ideal types. The first mode of coordination was portrayed as a 'battle for dominance' that strove for a tight linking of the industries involved. Using technological paradigms as an analytical lens to revisit this battle yields three insights:

First, the battle of dominance can be interpreted as an attempt to establish a novel and overarching paradigm for Smart Homes. As shown in 3.2, different technological solutions for a complete Smart Home competed to become the dominant design standard to guide the innovation process in the field. From a Kuhnian perspective, the failure of standardization is not unexpected. Paradigms, after all, are incommensurable; that is: the Kuhnian concept does explicitly exclude the possibility that different paradigm communities interact. Only two possibilities exist for the emergence of a new paradigm: the formation of a paradigm from a pre-paradigmatic stage, and the substitution of a new paradigm for an old one. Both mechanisms cannot function as a prototype in the Smart Home field as the field is neither in a pre-paradigmatic stage (after all, there are paradigms), nor would a Smart Home paradigm substitute for the existing ones. What Kuhn tells us about the failure of standardization in the Smart Home field, therefore, relates to the very nature of the standard that was striven for. The focus on technological solutions for the whole house neglected the fact that these solutions would comprise as components already standardized products, i.e. products for which technological paradigms have already been established. The 'battle for dominance' did not take into account the distributedness of the standardization attempts over distinct and relatively stable paradigms.

Secondly, and from a more practical point of view, the Kuhnian perspective draws our attention to the role of dominant designs in the Smart Home field. The technological solutions that were proposed in the 1990s constitute design proposals on the level of the product architecture; that is: a dominant design was sought after that would settle the arrangement of components within a Smart Home system. However, this perspective presumes that Smart Homes can be regarded as integrated systems whose general architecture can be described in terms of a design hierarchy fixing how components are mapped upon the system. The case analysis showed that this was, for several reasons, a misconception. Smart Homes are open systems for which a pre-stabilized design hierarchy cannot be the basis of the field's evolution. The systems sought after in the Smart Home field are open systems in the sense that there concrete phenotypes are not determined by the rules of a fixed architecture. The standardization attempts of the 1990s failed to address this particular feature of the field. It is thus not surprising that the 'battle for dominance' remained inconclusive.

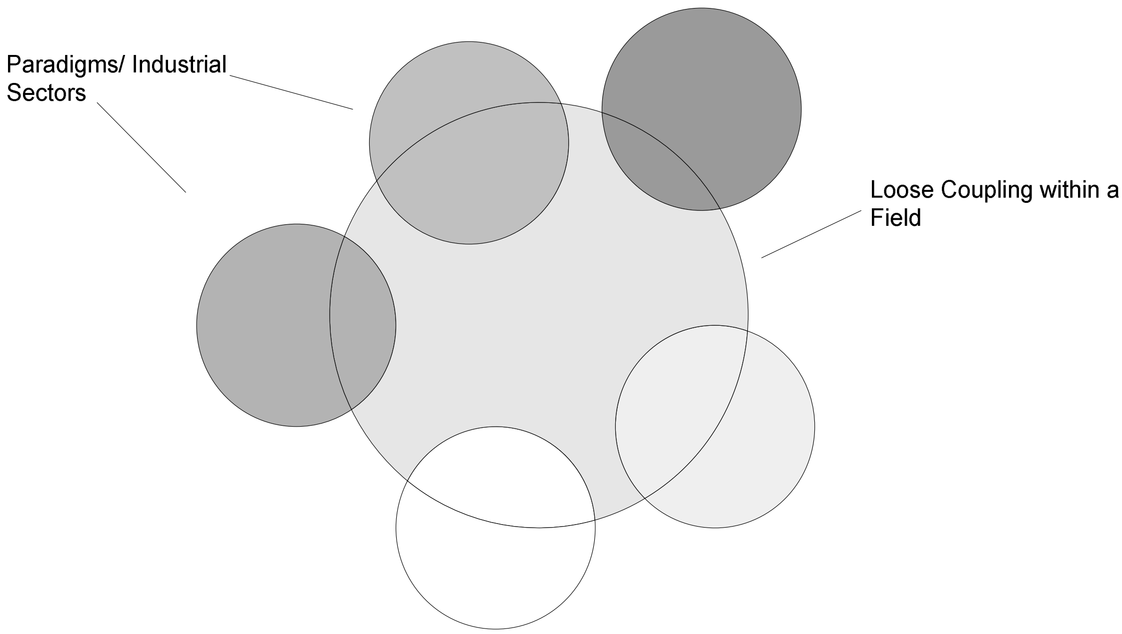
Thirdly, more general deliberations of the industry structure underlying the Smart Home field come into sight. Technological paradigms distinguish evolved industries from each other. However, the Smart Home field contains more than one such industry. This has an important consequence: The field's evolution cannot be described in terms of the conventional understanding of industry evolution, because it is not clear whether or not a new industry emerges substituting for the old one. This is a third lesson that can be learned from the Kuhnian perspective. I will briefly return to it in Section 5.

Summing up, the standardization attempts in the 1990s display a tight mode of coordination which tried to link distinct and evolved industries by establishing a Smart Home paradigm. But distinct industries cannot tightly be linked by means of a superimposed paradigm because it would substitute for the existing paradigms thereby displacing the existing industries. From a Kuhnian perspective, it could thus be shown that failure was inherent to the standardization attempts due to a misconception of the very nature of the Smart Home field.

4.3 Loose coordination: linking paradigms in the smart home field

Since the failure of standardization, the Smart Home field displays a different mode of coordination that more directly addresses the openness of Smart Home systems. Again, looking at this situation with a particular focus on technological paradigms yields a number of fresh insights. Especially, one important question is raised: *How, if not by means of a technological paradigm, is the innovation process coordinated that is necessary for the diffusion of Smart Home technologies and the evolution of the Smart Home field?* In other words: How can particular Smart Home systems be designed by distinct communities of specialists if design rules for the architecture of these systems are not available? The Kuhnian perspective thus identifies a key factor for the evolution of the Smart Home field. Learning has to be possible across the boundaries of distinct paradigms. This directs our attention towards structures that facilitate experience building from the interactions of distinct communities of specialists, and towards factors that enable the emergence of such structures (Figure 2). In this connection, the very concept of a technological paradigm has to be extended on a dimension that explains a loose coordination of paradigms, i.e. a dimension that explains a structure that links paradigms but leaves these paradigms intact. This is crucial to understand the evolution of open systems in general, and to come to grips with peculiarities of the innovation process in the Smart Home field in particular. Two practically relevant questions immediately follow: What can trigger the emergence of an innovation process through which the field would evolve? And: how is this innovation process coordinated provided the absence of a Smart Home paradigm?

Figure 2: Emerging Structure of the Smart Home Field



The case analysis demonstrated that *applications* are perceived to be a key element to fix the design parameter of specific Smart Home systems. From a Kuhnian perspective, this can be extended to a more general conclusion about triggers for the evolution and consolidation of the Smart Home field. *Application contexts* provide a source of knowledge about everyday practices and routines that can be utilized by different communities of specialists. As was shown above, the demographic aging is a widely accepted field of potential applications of Smart Home technologies. Demographic aging is appreciated in the field because it implies a significant market potential, i.e. an economic incentive to act upon this appreciation. This delivers an important conceptual cue: an application context provides a focused source of practical knowledge. In the case of the Smart Home field, a focused source about everyday practices and routines in private homes can be elicited from expected changes of these practices and routines due to the demographic aging.

The empirical analysis thus suggests that application contexts, once appreciated in a particular field of technology, facilitate a loose coordination of distinct paradigms. In that, they are similar to what Star (1993) calls 'boundary objects': an application context provides knowledge cues that can be processed by different paradigm communities. The exact effectiveness of this mode of coordination remains an issue for further research. However, the case analysis supports the following propositions: First, application contexts provide sources of knowledge to which different communities of specialists can relate. Specifically, they provide knowledge about arrays of everyday practices and routines that carry with them significant economic potentials, that is: the promise of an added value for prospective customers. Secondly, it is suggested that the locus of learning on the system level is delineated by focusing on valuable applications instead of technological solutions. In the Smart Home field, a notable shift occurred from a focus on technologies (Smart Homes as integrated systems) to a focus on specific product ecologies, i.e. applications (Smart Homes as open systems). For the different communities of specialists, it becomes a necessity to open up to the wider context in which they are embedded. Thirdly, the translation of application contexts into the design of specific systems thus becomes a core activity through which an overarching structure is superimposed to heterogeneous paradigm communities and through which these communities are loosely coordinated.

5. Conclusions

The empirical claims in this paper relate to the nature of open systems of technology. Based on an investigation into the technological field of Smart Homes, it was demonstrated that open systems of technology are embedded in innovation processes that involve distinct industries. This was described as a multi-industry setting that poses particular challenges for the coordination of the innovation process. For the Smart Home field, it could be shown that two different modes of coordination were successively attempted in the field. The first one – a tight mode of coordination by means of standardizing a dominant Smart Home design – failed due to a misconception. The open nature of the systems to be designed was not taken into account. The second one – a loose mode of coordination by means of linking industries – is still in an emergent stage. Defining applications instead of fixing technological solutions, however, appears to be a most striking feature of this mode of coordination.

Technological paradigms provide a sharp analytical tool to come to grips with the multi-industry setting of open systems' innovation processes. Consequently, the theoretical propositions concerned the nature and functioning of technological paradigms. It was shown that while technological paradigms are widely discussed in the innovation literature for the analysis of technological change *en bloc*, the very nature of normal technological progress is still poorly understood. Based on an exploration of the Kuhnian prototype, technological paradigms were introduced here as crystallizing when a dominant design standard is fixed within an industry. This parallels the priority that Kuhn gave to paradigms as examples: a design is the paramount element of a technological paradigm. Once fixed in design rules, it gives way to (more or less) homogeneous epistemic style that is shared within a community of specialists. The functioning of normal, i.e. paradigm bound, progress could thus be explored as one element within the general proceedings of technological change.

Technological paradigms can frustrate the emergence of innovation processes as they delineate industrial sectors from each other. For the Smart Home field, it could be shown that paradigms in well evolved industries foreclosed the emergence and fixations of a superimposed Smart Home paradigm. However, this did not cause innovative activities in the field to be abandoned. Instead, the focus shifted and the openness of the systems sought after was more directly addressed. Standards are no longer discussed as fixing technological solutions on a variety of parameters but rather as a platform on which specific applications can be defined. The innovation process in the field is thus coordinated by a loose linking of distinct technological paradigms.

The Smart Home field suggests that application contexts are an important facilitator for the coordination of distinct industries. This proposition is partially consistent with a Kuhnian perspective. For Kuhn, paradigm competition is resolved with reference to practical concerns outside the competing paradigms. This implies that there generally is an area of reference which can be processed by different, i.e. incommensurable, paradigms. However, Kuhn was very clear in stressing that paradigms can only compete and that only one paradigm would survive from such a competition. The Smart Home field that is characterized by distinct but not competing paradigms cannot completely be comprehended through the Kuhnian lenses.

The exact working of the proposed loose mode of coordination for multi-industry settings remains a point for further investigation. Especially, a conceptual device is needed that allows for more gradation of the actors' involvement with heterogeneous communities. Long before Kuhn's work on paradigms, and influential in many ways for that work (Kuhn, 1970: viii-ix; 1979), Ludwik Fleck described scientific communities as *thought collectives* characterized by a distinct *thought style* (Fleck, 1935). Thought collectives are in many ways similar to paradigms. However, Fleck put less emphasis on incommensurability than Kuhn and instead stressed that different thought collectives of varying stability overlap and intersect (Fleck, 1935: 105). This opens up avenues to understand the locus of the innovation process in the Smart Home field, i.e. the locus of learning about product ecologies. Using Fleck's perspective, the Smart Home field is driven by a less stable thought collective about specific applications that overlays the stable thought collectives (that is: paradigms) of the industries involved. From a theoretical point of view, I propose to consider the work of Fleck more closely in innovation research as an extension to the very idea of technological paradigms. This promises to be especially fruitful in coming to grips with the sociological implications of open system technologies which evolve on multiple and interdependent levels.

A more practical concern for further research is how application contexts actually affect design processes. While the multi-industry setting in the Smart Home field certainly poses challenges, it also bears chances because it forecloses the closure upon a predominant technological solution. At least potentially, this brings the innovation processes closer to the search for applications and to the definition of added value. However, whether or not this can be translated into the design of marketable systems depends on how well such a vague concern as everyday practices and routines (cf. Dewsbury et al., 2003) can actually inform design processes. The case explored in this paper could demonstrate that the link between everyday practices and design is slowly developing in the Smart Home field. Again: how this finally turns out remains an issue for further scrutiny of the Smart Home field.

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