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The transformative capacity of new technologies. How innovations affect sectoral change: Conceptual considerations

MPIfG Discussion Paper, No. 08/2

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Suggested Citation: Dolata, Ulrich (2008) : The transformative capacity of new technologies. How innovations affect sectoral change: Conceptual considerations, MPIfG Discussion Paper, No. 08/2, Max Planck Institute for the Study of Societies, Cologne

This Version is available at:
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MPIfG Discussion Paper 08/2

The Transformative Capacity of New Technologies

How Innovations Affect Sectoral Change: Conceptual Considerations

Ulrich Dolata

MPIfG Discussion Paper

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MPIfG Discussion Paper 08/2
Max-Planck-Institut für Gesellschaftsforschung, Köln
Max Planck Institute for the Study of Societies, Cologne
March 2008

MPIfG Discussion Paper
ISSN 0944-2073 (Print)
ISSN 1864-4325 (Internet)

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Abstract

Following up on recent debates about sectoral systems of innovation and production, the paper introduces a heuristic framework for analyzing and explaining distinct patterns of technology-based sectoral change. The concept is based on two interrelated influencing factors. The first is the sectoral-specific transformative capacity of new technologies themselves, that is, their substantial or incremental impact on socioeconomic and institutional change in a given sectoral system. The second is the sectoral adaptability of socioeconomic structures, institutions, and actors confronted with the opportunities presented by new technologies. The first factor – the sectoral transformative capacity of new technologies – enables us to identify the technology-driven pressure to change and adjust the structural and institutional architectures of the sectoral system. The second, complementary factor – sectoral adaptability – helps us to discern the distinct social patterns of anticipating and absorbing this technology-based pressure. The specific interplay between the two influencing factors creates distinguishable modes of sectoral transformation, ranging from anticipative and smooth adjustments to reactive and crisis-ridden patterns of change. Even processes of radical sectoral change continue over longer periods of mismatch, characterized by a cumulation of numerous and mostly gradual organizational, structural, and institutional transformations.

Zusammenfassung

In diesem Text wird ein analytischer Ansatz vorgestellt, mit dem das Ausmaß und die typischen Muster technikinduzierten sektoralen Wandels empirisch untersucht und erklärt werden können. Dazu werden zwei wesentliche Konzepte herausgestellt und aufeinander bezogen: Zum einen die spezifische sektorale Eingriffstiefe neuer Technologien, also die substanzielle oder inkrementelle Bedeutung, die diese für das jeweilige sektorale System haben (können); zum anderen die sektorale Adaptionsfähigkeit der dort etablierten sozioökonomischen Strukturen, Institutionen und Kernakteure, die mit neuen technologischen Möglichkeiten konfrontiert werden. Mit Hilfe des ersten Konzepts – sektorale Eingriffstiefe neuer Technologien – lässt sich der sektorale Anpassungs- und Veränderungsdruck, den neue Technologien beziehungsweise Technikfelder erzeugen, identifizieren. Mit dem zweiten komplementären Konzept – sektorale Adaptionsfähigkeit – lassen sich die sektorale Aufnahmebereitschaft und Verarbeitungskapazität dieses Drucks, die durch die jeweils bestehenden sektoralen Strukturen, Institutionen und Handlungsorientierungen geprägt werden, analysieren. Aus dem spezifischen Zusammenspiel beider Einflussfaktoren ergeben sich unterscheidbare sektorale Transformationsmuster, die sich im Spektrum antizipativer Anpassung und krisenhafter Reaktion bewegen.

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1 Technology-based socioeconomic and institutional change: Starting points

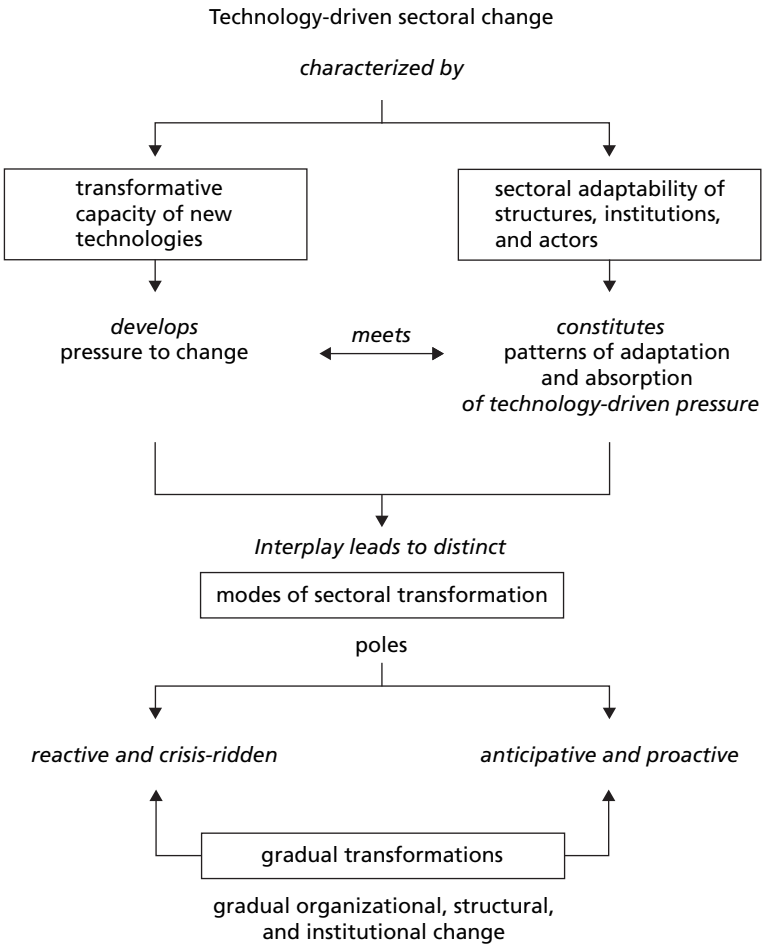
Since the late 1970s, the advanced capitalist societies have been marked by a continuing period of significant technological change, which is characterized to a great extent by the diffusion of numerous new information and communication technologies and, to a lesser extent, by new biotechnologies. In the course of the social shaping of these new technologies, the strategies and organizational fits of the involved actors, as well as the socioeconomic and institutional settings in which they are embedded, have also undergone significant changes. Although they are the contingent results of actor-based social processes, new technologies have at the same time contributed to the restructuring of existing economic, political, and social surroundings: they have promoted organizational change and new patterns of interorganizational collaboration, created leeway for new actors, constituted new markets and patterns of competition, modified lifestyles and consumption in a way that has often required far-reaching readjustments of legal frameworks, and sometimes provoked sharp disputes about their benefits and risks (Dolata/Werle 2007).

Meanwhile, this general interrelation of technological, socioeconomic, and institutional changes is to be found in various scientific concepts on the co-evolution of technology and institutions or in recent sociotechnical system approaches. In various ways, they raise the question of "how technology is shaped by social, economic, and political forces alike; and how, in the same process, technologies and technology systems shape human relations and societies" (Rip/Kemp 1998: 328; Kemp/Rip/Schot 2001; Kitschelt 1991; Nelson 1994; Lynn/Aram/Reddy 1996; Geels 2005). Although the general interrelations between technology and society – or, more specifically, between technology, socioeconomic structures, and institutions – are of interest in these approaches, they still aim to study and explain the processes and modes of *technological change*. However, there have rarely been answers to the second part of the question concerning processes of *socioeconomic and institutional change* provoked by emerging new technological opportunities and constraints (Werle 2005). How and to what extent are the involved socioeconomic structures, institutions, and actors changing under the influence of new technologies? How do they react to such a technology-driven pressure to change?

These questions are discussed in the following with regard to the technology-driven *transformation of sectoral systems*. This focus on the mesolevel of economic sectors makes allowances for the observation that, in particular, new multipurpose technologies affecting different sectors do so in distinguishable ways. In each case they exert a specific pressure to change on the structures, institutions, and actors of the various

This paper is a result of a research project entitled "Internet and Biotechnology: Technological innovations and their impact on actors, cooperation, and competition in comparative perspective." It has been funded by the German Research Foundation (DFG) and will be concluded in Summer 2008.

Figure 1 Technology-based sectoral change: Basic categories



existing sectoral systems. In addition, this pressure to change is perceived and handled in distinct ways within each given sector.

Based on this consideration, the paper aims to introduce and empirically substantiate an *analytic framework* for studying and explaining technology-driven sectoral change. The framework depends on two interrelated influencing factors:

– The first is the sectoral-specific *transformative capacity of new technologies* themselves. While a technology may have a supplemental and sustaining impact on the structures and institutions of one economic sector, it may be disruptive in others and provoke major adjustment crises and changes.

– The second and complementary factor is the *socioeconomic adaptability* of the established sectoral structures, institutions, and actors confronted with the challenges presented by new technologies. While some sectoral systems and its established actors may, at an early stage, ignore and underestimate even serious technological chal-

lenges, others may possess institutionalized mechanisms that even facilitate path-deviant transformations.

The first concept – the transformative capacity of new technologies – enables us to identify the technology-driven pressure to change and adjust the structural and institutional architectures of a given sectoral system (part 3). The second, complementary concept – sectoral adaptability – helps us to discern the distinct social patterns of anticipating and absorbing this technology-based pressure. The specific interplay between these two influencing factors creates distinguishable *modes of sectoral transformation*, ranging from anticipative and smooth adjustments to reactive and disruptive patterns of change (part 4). However, even processes of radical sectoral change continue over longer periods of mismatch, characterized by a cumulation of numerous and mostly *gradual organizational, structural, and institutional transformations* (part 5).

2 Sociotechnical systems and periods of mismatch

The automobile industry, the aircraft and aerospace industries, the chemical and pharmaceutical industries, and the music and media businesses are not simply socially based sectoral systems; they are sociotechnical entities. Characteristic of the constitution of sectoral systems are not only distinct socioeconomic structures and institutions, typical constellations of actors, and patterns of actor-based interaction, but also the specific technologies being developed, produced, or used. The types of technologies that characterize a given sector promote specific patterns of industrial and socioeconomic organization. Large-scale and capital-intensive technologies (such as aircraft and aerospace technologies) cannot be developed, applied, and organized in such a decentralized and market-based way, for instance, as can small-sized and cross-sectional technologies (such as biotechnology). Far into the 1980s, progress in decentralizing and liberalizing large technical systems, such as telecommunications or energy supply, remained limited, especially because of technology-based boundaries. Science-based sectors, such as the pharmaceutical industry, are characteristic of strong academic-industrial relationships, whereas other sectors depending on application-oriented knowledge, such as manufacturing systems engineering, are not. Finally, sectors that develop, manufacture, or depend on individually useable consumer technologies, such as entertainment electronics or the music and media industries, are largely shaped by their idiosyncratic utilization by private consumers, whereas sectors producing large-scale technologies and industrial goods are not.

Thus, the distinct technological profiles appear to be one of the major factors influencing and shaping the socioeconomic structures, institutions, actors, and interactions of sectoral systems. Christopher Freeman and Carlota Perez (1988) have conceptualized this interrelation as a *match:* To operate successfully, sociotechnical systems of any kind

have to show compatibility between the peculiarities of their technological profile, their socioeconomic structures, and their institutions. With regard to the development of large technical systems, Renate Mayntz (Mayntz/Hughes 1988; Mayntz 1993) points out that their socioeconomic structures and institutions are highly dependent on the respective technological attributes characteristic of the sociotechnical system. Herbert Kitschelt (1991: 468) considers this *match* to be a prerequisite for efficiency: "Industrial sectors, identified by core technologies, efficiently operate only if governance structures match technological constraints."

Whereas incremental or sporadic radical innovations can normally be integrated into existing contexts without major socioeconomic and institutional modification and do not fundamentally challenge the existing sociotechnical match, the well-rehearsed interplay between established technological profiles and socioeconomic structures, institutions, and activities becomes unsettled in times of paradigmatic and systemic technological change. Both fundamentally new and also substantially enhanced technologies challenge the operativeness of existing sociotechnical constellations, necessitate far-reaching socioeconomic and institutional adjustment processes, and are effective as discrete incentives of socioeconomic and institutional change. Freeman and Perez conceptualize such far-reaching states of flux as *periods of mismatch*: longer phases of searching for, experimenting and struggling with new structural and institutional arrangements that correspond with the new technological opportunities and constraints. As a result of such adjustment processes, a new equilibrium between technology, socioeconomic structures, and institutions emerges over time: "Social and institutional changes are necessary to bring about a better 'match' between the new technology and the system of social management of the economy – or 'regime of regulation'" (Freeman/Perez 1988: 38; Perez 2002; see also: Rip/Kemp 1998; Kemp/Rip/Schot 2001).

This overall stylization of sociotechnical transformations is an important starting point for analyzing technology-based sectoral change; at the same time, it is somewhat unsatisfying for our subject of study. The match/mismatch concept mainly refers to the meta-level of economic systems or societies. The distinct sectoral impacts of new technologies tend to disappear from view. Moreover, the concept also shares a problem typical of co-evolutionary approaches (Nelson 1994; for an overview: Geels 2004). It remains vague when describing and explaining the concrete patterns, variants, and dynamics of socioeconomic and institutional restructuring initiated by the emergence and stabilization of new technological opportunities.

In contrast, when we analyze technology-driven change at the sectoral level, we have to take into consideration that ubiquitously useable new technologies may have significantly different repercussions on the structural and institutional arrangements of different sectors. For instance, the sectoral pressure to change and adapt triggered by the Internet is much more dramatic in the music and media business than in the automobile industry (BRIE-IGCC E-conomy Project 2001; Dolata 2005a). Moreover, it should be borne in mind that technologically based pressure to change and adapt depends on

the established structural and institutional reality of a sector and on the dominant patterns of activity herein. Therefore, it can be perceived and treated in different ways. The development and use of new biotechnologies in the U.S. pharmaceutical sector since the late 1970s, for instance, faced more anticipative and adaptive sectoral structures, institutions, and actors than the respective sectoral systems in Western European countries (especially Germany). In the aftermath, these differences led to nationally differing needs and modes of sectoral transformation (Henderson/Orsenigo/Pisano 1999; Barben 2007; see also: Hollingsworth/Streeck 1994).

3 New technologies and their transformative capacity

The match/mismatch approach conceptualizes the influence of new technologies on socioeconomic and institutional change as pressure on existing structures, institutions, and actors to change and adjust. However, when we focus on the mesolevel, it becomes obvious that, at times, the pressure of the same set of technologies on various economic sectors differs significantly (Mowery/Nelson 1999).

The concept of sectoral transformative capacity helps identify and analyze the distinct sectoral relevance of new technologies, as well as their specific pressure to change and adjust the existing sectoral structures, institutions, and activities. To render more precisely the transformative capacity of new technologies, I introduce two distinctions. First, we have to determine the extent to which the development and the use of new technological opportunities coincide or diverge. Are new technologies being developed primarily within the sectoral system *(endogenous technology)*, or do they originate significantly outside the sector using them *(exogenous technology)*? Second, we have to search for the sectoral effects of new technologies. Do they tend to have indirect, subsidiary, and functionally supportive effects *(low transformative capacity)*, or do they exert a direct, incisive, and generally disruptive pressure on the established sectoral system, its structures, institutions, and actors *(high transformative capacity)*?

Specification I: Endogenous versus exogenous technology

Addressing these questions involves using a broad concept of economic sectors that comprises *two major types of sectoral systems.*

On the one hand, some economic sectors can be characterized by a high degree of innovative activity within the system, examples being the chemical and pharmaceutical sectors, the automobile industry, the energy and telecommunications sector, or the aerospace industry (Malerba 2004). In these sectors, usually referred to as sectoral in-

novation systems, technology-driven sectoral change may derive both from internal innovation processes and from new technologies developed in other sectors – especially new information and communication technologies – which are tailored to the specific demands of the sector. A typical case in point is the current change of energy systems. This is based on the system-internal development of new decentralized and flexible energy production technologies, as well as on the implementation of new system-external founded information and communication technologies, which at the same time foster new possibilities for the centralized management of complex and distributed energy systems (Rohracher 2007).

On the other hand, there are other important economic sectors that cannot be characterized as innovation systems. Instead, they mainly use technologies developed elsewhere and adapt them through processes of co-invention in a sector-specific way (Greenstein/Prince 2006; Goldfarb 2005; Oudshoorn/Pinch 2003). This is characteristic of the music and media industries or banking and finance, where new technologies inducing sectoral change mostly spill into the sector from the outside. Since these sectors mainly use externally developed technologies, their functionalities too can be critically altered by new technological opportunities. Once again, information and communication technologies in particular can trigger substantial processes of restructuring.

In relating the contexts of origin and application to each other, we can work out the role and relevance of internally and externally developed technologies effecting sectoral change.

First, the development and use of new technologies can be essentially a sector-immanent phenomenon. In such instances, the technologies are not only used in a sector-specific way but have also been developed within the sector. Pharmaceutical biotechnology is a case in point. In the 1970s, biotechnology emerged at the edges of the pharmaceutical sector, driven by academic research and new start-up companies. Since the 1980s, it has been further developed and used within the pharmaceutical sector, which now consists of established companies together with new biotechnology firms and cooperating institutes of academic research. The interplay between technological innovations, socio-economic and institutional change, which has led to a far-reaching restructuring of the pharmaceutical sector during the last twenty years, can be conceptualized mainly as a sector-immanent process (Dolata 2003; Henderson/Orsenigo/Pisano 1999).

Second, new technologies may also have been developed outside a sector and made a functional and subsidiary impact on the system without changing its structural and institutional constitution or the position of its core actors in an incisive way. A typical case in point is the gradual replacement of electronic data interchange systems (EDI systems) that coordinate the companies' internal or external trade relations in the automobile industry by means of Internet-based technologies. While in this case the gradual introduction and increasing use of new Internet-based networking technologies may well be accompanied by modification of production, logistics, and distribution process-

es, it does not bring about widespread sectoral pressure for restructuring (E-Business Watch 2005).

Finally, technologies from outside a sectoral system may grow into new basic technologies that will be constitutive for the further reproduction of a sector and therefore become a major stimulus for a far-reaching process of sectoral restructuring. This is characteristic of the current transformation of the music business as a sector primarily reliant on externally developed technologies. Digitalization, data compression, and the Internet have initiated far-reaching restructuring dynamics that have captured the whole sector and its established actors. Characteristic of this period of transition are the search for new business models and patterns of distribution, significant changes in the sectoral modes of competition and collaboration, and broad readjustments to regulative and legal frameworks. This case shows also that new technological opportunities can appear as an exogenous shock to the sector and initiate an extensive process of restructuring and opening (Tschmuck 2006: 149–177; Burkart/McCourt 2006).

Specification II: Low versus high transformative capacity

Carrying the idea a bit further along the line of the examples mentioned, we can render their sectoral transformative capacity more precisely by combining the (potential) sectoral applications of new technologies, wherever they originate, with the sectoral restructurings required to develop, implement, and use them efficiently.

New technologies, whether they originate from inside or outside the system, can exert direct, incisive, and generally disruptive pressure to change on the overall functionality of existing sectoral systems, their structures, institutions, and actors.

The impact of new biotechnologies on the pharmaceutical sector since the late 1970s is a case in point. This paradigmatically new stream of technologies has not only changed the technological profile of the sector significantly – from chemical synthesis to biotechnology – but has also altered its guiding principles *(Leitbild)* – from chemistry towards a life-sciences orientation. Their grounding in basic research, together with their multidisciplinary and decentralized dynamics, have increased the relevance of academic science for the reproduction of the sector, have fostered the emergence of specialized biotechnology firms and thus increased the necessity for intra-industrial as well as academic-industrial cooperation, and have put the established pharmaceutical enterprises under pressure to reposition their strategies, to open up culturally, and to engage with new modes of cooperative research and development activities uncommon before. Last but not least, the rise of biotechnology has required new regulatory and legal frameworks for research and commercialization (Orsenigo 1989, 1993; Mc-Kelvey/Rickne/Laage-Hellmann 2004). All these substantial structural and institutional changes within the pharmaceutical sector have been caused essentially by new scientific and techno-

logical opportunities: an instance of great transformative capacity on the part of a new set of technologies. The same applies to the structural and institutional transitions outlined in the music and media sector, which are due to digitalization, data-compression, and the Internet.

However, new technologies may have only an indirect, supportive, and subsidiary sectoral impact and may fail to challenge a sectoral system and its established structures, institutions, and actors in any substantial way.

The effect of Internet-based technologies on the automobile sector, for instance, has been relatively minor. Internet-based technologies replace existing EDI systems for the coordination of transaction processes and manufacturer-supplier collaborations. Furthermore, they allow for the buildup of new electronic marketplaces and are used extensively in the retail market and as tools for company presentation. However, they do not seriously affect the technological profile, the structural and institutional arrangements, the corporate activities of the focal actors, or the guiding principles of the sector (Helper/MacDuffie 2001; E-Business Watch 2005). Internet-based technologies are being introduced and implemented unpretentiously in existing market processes, business connections, and networks – illustrating a case of low transformative capacity on the part of new technological opportunities from outside the sector.

The examples show that the transformative capacity of new technologies is not an autonomous category, deterministically derivable from the specifics of the technology concerned. Instead it is a relational category defined by both the characteristics of the technology involved and the structural and institutional constitution of the sector on which the technology has an impact. In addition, the transformative capacity of new technologies is a heuristic category, incapable of quantitative measurement. But it can be rendered more precisely in terms of qualitative criteria. Empirically analyzing modes and paths of technology-induced sectoral change therefore requires us to examine the extent to which new technological opportunities and their attributed peculiarities

– alter the technological profile of the sector and enhance or destroy the existing knowledge base and competencies;
– affect the existing patterns of research and development, production, distribution, and market relations;
– promote the emergence of new actors, pressure the established ones to change strategically, and contribute to the rearrangement of the sectoral figurations of actors at large;
– facilitate or enforce new patterns of cooperative and competitive interaction;
– initiate institutional readjustments (e.g. new regulative and legal frameworks or modified guiding principles, norms, and beliefs);
– open up or widen the existing borders of the sectoral system, thereby provoking a more intense interpenetration of different systems.

In sum, the concept of transformative capacity brings technology into its own as a relevant factor that influences socioeconomic and institutional transformation on the level of sectoral systems. Therefore, the *first central idea* of this paper highlights the view that new technological opportunities relevant to a given sector modify the existing match between technology, structures, and institutions in the course of their formation and adoption. In particular, multipurpose technologies (such as the Internet) or new sets of technologies affecting several sectors (such as the new biotechnologies) open up different and specific sectoral horizons of use and application. The more a new technology affects the existing patterns of economic activity in a given sectoral system and the less it is able to be implemented, used, and efficiently exploited within its existing institutional framework, the greater the pressure is on the sector to undergo significant change. I refer to this power to provoke change as the transformative capacity of a new technology.

4 New technologies and sectoral adaptability

This says nothing, however, about the handling of new technological challenges confronting a sector and its established actors. New technological opportunities that fail to fit the established social and institutional framework of a sector cause mismatch, irritation, and the need for action beyond well-rehearsed guiding principles, rules, norms, and routines (Ortmann 2003), and thus constitute the above-mentioned periods of mismatch also on the sectoral level. Still, they do not necessarily lead to new sectoral structures and institutions that are adequate and operate efficiently – this would be a deterministic deduction. Instead, new technological opportunities often deviate from established and persistent paths of sociotechnical development and have to be discerned, interpreted, and picked up by the actors involved.

This may happen by different means. Existing sectoral systems and their actors may be characterized by structural, institutional, and cognitive openness and adaptability, which encourages the early perception and adoption of new technological opportunities. At the other end of the scale, we find sectors that are characterized by persistence and structural conservatism on both the system and actor levels, which impedes early and directed sectoral change and causes crisis-ridden adjustment processes instead.

These considerations lead to the *second central idea* of the paper. The handling of new technological opportunities as well as the dynamics and typical paths of technology-driven transformations actually depend on the adaptability of the established sectoral structures, institutions, and actors confronted with the challenges presented by new technologies: on the structural and institutional openness of the respective sector to path-deviant sociotechnical developments and on the capability of the actors involved at anticipating, adopting and integrating the new technology.

Specification I: Low adaptability

It is by no means atypical that the potential capacities and structural effects of new technological opportunities which significantly deviate from the established sociotechnical profile of a sector are slowly perceived and accepted – both on the system level and by the key sectoral actors involved (Hannan/Freeman 1984; Leblebici et al. 1991; Christensen 1997; Mellahi/Wilkinson 2004). At an early stage, a sectoral system and its established actors may ignore and underestimate even serious technological challenges, especially ones that fail to fit with established institutions and strategic approaches known to have been successful in the past. Examples of such a highly transformative capacity on the part of a new set of technologies and, at the same time, low adaptability both on the sectoral level and the level of core actors are the failure of IBM to anticipate the PC revolution in the late 1970s, the German chemical and pharmaceutical industries' initial discounting of the serious impact of biotechnology, and the recent struggle of the music industry to come to terms with the impact of the digital and Internet revolution.

Until the late 1970s, the computer industry was dominated by one big industrial player: IBM. Although the group was the industry's monopolistic technology leader, its management underestimated the development and market opportunities of the personal computer at this time and decided not to develop in-house or buy exclusively relevant system components – microprocessors and operating system software – but, instead, to license them from the outside vendors Microsoft and Intel. The two newcomers were free to sell their products to other vendors. The unexpected outcome for IBM was not only a loss of control over the further development of PC standards; it also meant the advent of the imposing track record for Microsoft and Intel as market-dominating actors in the software and semiconductor industry. At the same time, it became the starting point of a far-reaching restructuring of the computer industry with the establishment of new computer manufacturers (such as Compaq, Dell and Hewlett-Packard) and sharp competitive dynamics throughout the restructured sector (Ichbiah/Knepper 1991; Langlois/Robertson 1992; Kenney/Curry 2001). In this case, a hitherto extremely successful and powerful focal actor failed to anticipate a technological breakthrough in time, together with its socioeconomic and societal implications. This brought about a far-reaching restructuring and differentiation process within the sector and a significant decline in power on the part of its former central actor.

In contrast, the hesitant dealings with new biotechnologies in the German chemical and pharmaceutical industries during the second half of the 1970s and the first half of the 1980s illustrate a case not only of low anticipatory ability on the part of the focal actors but also of low adaptability of the sector as a whole. Well into the 1980s, the sector lacked any systematic link between the highly qualified basic research being conducted at the universities and industrial research and development activities in the firms. At the same time, the emergence of new start-up companies – the seismographs and first movers in new technologies – was hampered by an underdeveloped system of venture capital financing and by a strong and almost purely academic self-conception and orientation

of the scientific community itself. Moreover, characteristic of the established German chemical and pharmaceutical companies far into the 1980s was a marked indifference and incomprehension concerning the potentials and advantages of new biotechnologies. An internationally strong position in organic chemistry and deep skepticism on the part of the top-level management at major corporations (which were dominated by chemists) of the mindset of biologists made it hard for these corporations to see the dynamics and socioeconomic restructuring potential of the new biotechnologies (Buchholz 1979; Dolata 1996, 2003; Briken/Kurz 2006). The absence of start-up companies and venture capital, an underdeveloped transfer of knowledge between academia and industry, only minor experience with external and science-based collaborations on the part of big pharmaceutical companies, authoritarian and hierarchical corporate structures and a strong focus on chemistry by the top management of these companies blocked organizational and institutional restructuring and contributed to a hesitant and crisis-ridden transformation process – both on the sectoral and the firm levels.

Another case in point is the current transformation of the music industry. For decades the structural and institutional framework of the sector was stable. It consisted of a few vertically integrated record companies discovering and promoting musicians, producing LPs and/or CDs in their own recording studios and distributing their products through worldwide distribution channels. They were supported by closely related retail businesses selling the products and by rigorous and efficient copyright laws. These relatively stable settings have been eroding since the end of the 1990s. Three complementary technological developments are accountable for this. Nowadays music is a digital product that can be copied repeatedly without loss of quality. Furthermore, new standards of data compression allow for an unproblematic exchange and download of all but the most data-intensive products. In addition, the Internet has proved to be the ideal medium for exchanging such products worldwide. Instead of grasping the new opportunities of digital marketing and distribution early on and positioning themselves in time as leading players of a restructured sector, the focal actors, especially the major record companies, ignored the emerging technological challenges at an early stage and subsequently interpreted them as a danger to be averted. As a consequence, the major impetus for digital distribution of music via the Internet did not emerge out of the core of the sector but was promoted and pushed instead by new actors from the fringes or from outside the sector. Initially these were noncommercial file-sharing services (like Napster, KaZaa, Gnutella), which opened a new door by subversive means. Since then, well-known enterprises of other sectors have stepped in: Apple, Microsoft, T-online, and wireless carriers like Vodafone (Tschmuck 2006; Burkart/McCourt 2006; Benkler 2006). In this case, too, technology-driven sectoral change can be characterized as a crisis-ridden adjustment process. The existing sectoral structures and institutions – the patterns of competition and cooperation, the modes of distribution or copyright, for example – are being made obsolete to a large extent by sector-external technological developments and are challenged first of all by actors from outside the core of the system.

These are examples of the high transformative capacity of new technologies and, at the same time, of the low adaptability of the existing sectoral structures, institutions, and focal actors. The established socioeconomic structures and institutional arrangements characteristic of the sector and constitutive of its functioning have been very stable and successful over a long period of time. However, with the emergence of paradigmatically new technological opportunities that do not fit into the established sociotechnical system, they are becoming not only dysfunctional but are also proving to be persistent and change-resistant. Characteristic of these sectors is a lack of structural and institutional early warning systems that would enable them to perceive and process major technological changes and the accompanying socioeconomic pressure in a timely manner. The focal actors of the sector are directing their strategic behavior at already existing structures, rules, and guiding principles. Their activities are strongly based on strategies known to have been successful in the past. Therefore, they often react to new developments with blockades or "cartels of fear" and do not, as a rule, start redefining their strategic behavior until confronted with massive and irrefutable pressure to change.

All this has been amply discussed in the debates about organizational failure (Mellahi/Wilkinson 2004) and the path dependency of technologies or institutions (Werle 2007; Beyer 2006; Thelen 2003). In conjunction with these discussions, I refer to this pattern of low sectoral adaptability as *transformation-resistant path dependency*. Neither on the system level nor on the level of focal actors are there sector-immanent mechanisms of transformation enabling and promoting sociotechnical path deviance or change. Characteristic of these sectors is a strong bias towards stability and, simultaneously, a high level of vulnerability caused by the development of path-deviant technologies, which leads to crisis-ridden processes of transformation (Beyer 2006). In these cases, technology-induced sectoral change is not a directed process controlled by the focal actors. Instead it is driven by major crises of structural and institutional adjustment and significantly advanced by actors from outside or from the periphery of the sector. It is also driven by technological shifts not developed at the center of the sectoral system, by cutting-edge actors from the peripherals of the system who use and commercialize the new technologies as first movers (e.g. subversive subcommunities or start-up companies) or by powerful external actors infiltrating the sector and changing significantly the existing figurations of actors and their power relations. On the level of strategically operating actors, transformation-resistant sectors face different degrees of adaptability. While low adaptability is typical of the saturated focal actors of the system, cutting-edge actors who are not yet established are characterized instead by a high degree of sensitivity and receptiveness to new technologies. These actors regard new technologies as opportunity structures and, in this case, appear to be the main drivers of sectoral change.

Specification II: High adaptability

Alternatively, a sectoral system and its established actors may possess institutionalized mechanisms of anticipation and adaptation that even facilitate path-deviant transformations. This is typical of sectoral systems that feature strong and institutionalized mechanisms of competition, innovation, and experimentation which are already incorporated in its existing structures and institutions. The existence of such mechanisms facilitates both the requirements and mentalities of open-mindedness and sensitivity towards new and path-deviant technological opportunities and therefore already encourages socioeconomic and institutional restructurings at an early stage. Once again, I will explain this initially by way of example.

Characteristic of the automobile industry is not only an asymmetric power structure but also great pressure to compete and innovate – on the part of both manufacturers and suppliers. Rivalries are not simply fought out through price competition but, primarily, in races for new technology and innovation. On the product level, competition arises through the development and introduction of new models, which is driven to a large extent by the introduction of electronic devices. On the process level, competition is forced by improvements in productivity and efficiency in intra- and intercorporate processes of coordination that depend heavily on the implementation of advanced information technology networks (Jürgens/Meißner 2005; Pries/Hertwig 2005). This high degree of competition and innovation characterizing the sector has led to an open-mindedness and receptiveness on the part of its focal actors with regard to new product and process technologies. The early and comparatively unproblematic embedding of Internet-based technologies in the business practices and collaboration structures of this sector fits this picture. The high degree of competency among manufacturers and focal suppliers in introducing and implementing new electronic network technologies, together with their long experience in organizing complex collaborative arrangements, has supported the introduction and use of Internet-based technologies as a calculated top-down process conducted by the focal actors of the sector – and not as a crisis-ridden adjustment process (Helper/MacDuffie 2001; e-Business Watch 2005). This is a case of high adaptability on the part of the sector as a whole and, similarly, high anticipatory ability on the part of its focal actors.

Likewise, the indisputable pioneering role and international dominance of the U.S. pharmaceutical industry in the development and commercialization of new biotechnologies is a result of a distinctive ability on the part of the sectoral (and national) structures and institutions to anticipate and adapt. Starting at the end of the 1940s, intensive and long-term public research funding in health care conducted by the National Institutes of Health (NIH) has been supportive in establishing biomedical research centers at universities. Moreover, a traditionally strong commercial orientation of the U.S. university system has promoted technology transfer efforts from academia to industry. Furthermore, since the 1970s, start-up companies in the computer and information-technology industries have been established as driving forces of innovation processes

and, together with functioning venture-capital markets, have inspired and promoted the formation of specialized biotechnology firms. In the same way, the development of regional biotechnology clusters since the end of the 1970s has been able to build on earlier experiences gained in the computer and semiconductor industries. Lastly, these structural and institutional environments have facilitated the comparatively early receptivity of the big pharmaceutical corporations to the potential of new biotechnologies, to a restructuring of the incumbent firms, and to new patterns of cooperation between established companies and new start-up firms (Kenney 1986; Orsenigo 1989; Giesecke 2001; Barben 2007). Unlike the above-mentioned German case, the high degree of sectoral transformative capacity of a new stream of technologies met in the U.S. with a high level of adaptability and anticipation on the part of the sectoral (and national) structures, institutions, and actors.

Characteristic of anticipative and adaptive sectors are not only the structural and institutional support of continuity and stability, but, at the same time, the existence of strong and institutionalized *mechanisms of transformation* that facilitate even path-deviant sectoral change. Of course, the specific structural and institutional mechanisms of transformation that contribute to a high adaptability may vary between sectors (and also between the different national systems in which the sectors are embedded). Nevertheless, along with the examples outlined, we can distinguish among the following typical mechanisms of transformation.

High intensity of innovation and competition. Sectors characterized by strong and continuing dynamics of technological innovation and economic competition offer time and again first-mover advantages, constitute playgrounds for new cutting-edge actors, and force all parties to permanently review and adjust their strategies, organizational structures, interorganizational relations, and institutional arrangements. In such sectors as the pharmaceutical, computer, and semiconductor industries, structural and institutional change today is not an exceptional phenomenon; it is a permanent challenge (Lüthje 2007; Breshanan/Malerba 1999).

Transformation-supporting industry structures. Sectors that characteristically feature a co-existence of different types of firms (large, medium-sized, and start-up enterprises), institutionalized playgrounds for innovators and cutting-edge actors in technology niches (supported, for instance, by functioning venture-capital systems or public funding and promotion), and strong traditions of formal and informal collaboration between heterogeneous actors (for example, between industry and academia, big business and start-ups, manufacturers and suppliers, or producers and consumers) possess structural and institutional early-warning systems that stimulate anticipation and adaptiveness and facilitate the proactive handling of the sociotechnical challenges provoked by new technological opportunities (Hall/Soskice 2001; Garud/Karnoe 2001; Mowery/Nelson 1999).

Horizontally structured and collaboratively embedded focal actors. Characteristic of sectors dominated by vertically integrated and in-house-oriented major enterprises (such as the German pharmaceutical industry up to the 1980s or the music industry to date) is a strong self-centered attitude on the part of their core actors. Therefore, they exhibit less openness and adaptability to technological innovations than in sectors characterized by horizontally structured enterprises that are involved in numerous collaborations that have to be permanently readjusted (such as the automobile, computer, or semiconductor industries). The latter requires the focal actors to have high-level competency in coordinating, guiding, and (re)structuring complex collaborative dynamics. It enhances sensitivity and receptivity to new technological opportunities and their continuous implementation in the existing intra- and interorganizational structures (Christensen 1997).

Institutionalized mechanisms of transfer between academia and industry. The dynamics of science-based sectors depend heavily on industry's ability to absorb, apply, and further develop advanced academic knowledge. The more institutionalized, normal, and self-evident collaborations between academia and industry are, the more anticipative and adaptive the sector will be. This involves formalized rules and norms of academic-industrial collaboration, as well as informal mechanisms of interpenetration between academia and industry (Kenney 1986).

Technology, innovation, and competition policy. Political framings may also ultimately enhance sectoral adaptability. Examples of this would be technology and innovation policies that do not focus on backing national champions but instead promote strategic technology niches and cutting-edge actors. Other examples are competition policies aimed at preventing monopolies and mediation policies that support the resources and competencies of private users and innovative subcommunities and systematically include them in public policy decision-making (Dolata 2005b; Larédo/Mustar 2001; Kemp/Rip/Schot 2001).

The existence of appropriate structural and institutional mechanisms of transformation increases the chances that sectoral systems will not be overwhelmed by the pressure to adapt and change that is exerted by new technological opportunities. Instead, mechanisms of transformation may help to discern and pro-actively seize these opportunities at an early stage. In this case, a crisis-ridden reaction to an exogenous shock is not characteristic of sectoral change, but rather the open-minded use and advancement of new technological alternatives accompanied by an equally open-minded search for matching structural and institutional arrangements. I refer to mechanisms that promote the sectoral ability to adapt, adjust, and integrate new deviant technologies in an early phase as *transformation-supportive path dependency*. However, even in this case, sectoral change is not at all a harmonious process. On the contrary, sectoral change is characterized by its intensity of innovation and competition, is interspersed with power struggles, is highly selective and often encourages far-reaching readjustments to the existing constellations of actors and patterns of competition.

5 New technologies and patterns of sectoral transformation

By means of the two concepts introduced – the transformative capacity of new technologies and sectoral adaptability – technology-driven sectoral change can be conceptualized and empirically analyzed as an iterative interplay of technological dynamics and accompanying social processes of institutionalization and structuration. In addition, by dint of the supplementary *concept of gradual transformations*, technology-driven sectoral change can be analyzed as a successive process of organizational, structural, and institutional readjustment in the intermediate range between path-dependent continuities and radical breaks.

This is relevant because, since the second half of the 1970s, technology-driven change in many sectors is no longer the exceptional, rare disruption of long periods of sociotechnical continuity and stasis, but has become a lasting and formative normality. However, even serious sectoral change is not characterized by unique, short-term, and eruptive sociotechnical breaks opening rapidly into a new period of stability with, once again, only marginal adjustments. Moreover, typical of sectoral change is not the breakdown or radical replacement of existing structures, institutions, and actors. Instead, technology-driven sectoral change is typified by longer periods of discontinuity featuring a multitude of gradual transformations, where the organizational, structural, and institutional bases of a sector are successively renewed in the direction of a new and dominant design. Furthermore, it is against the background of the sustained dynamics of technological innovation that the new designs are continually put to the test and changed anew.

Specification I: Gradual transformations

Dichotomous typologies that only distinguish between long-lasting periods of structural and institutional stasis and rare periods of radical and abrupt change due to exogenous shocks (Pempel 1998; Krasner 1988) are unable to analyze real patterns and modes of technology-based sectoral change effectively. They mask the really interesting interstice between structural and institutional stability, on the one hand, and radical system shifts, on the other.

This is the starting point for the concept of gradual institutional transformation developed by Kathleen Thelen and Wolfgang Streeck (Thelen 2003; Streeck/Thelen 2005). Their object of investigation is the current transformation of advanced capitalist economies since the 1980s, which "unfolds by and large incrementally, without dramatic disruptions like the wars and revolutions that were characteristic of the first half of the twentieth century" (Streeck/Thelen 2005: 4). Admittedly, longer periods characterized by a multitude of gradual transformations are anything but negligible and may change the institutional constitution of modern capitalist systems significantly over time.

Therefore, "incremental change with transformative results" (Streeck/Thelen 2005: 9) is revealed to be a generally typical mode of transformation in modern capitalist societies (see also Djelic/Quack 2007).

Against the background of empirical case studies, Streeck and Thelen (2005: 18–33) present a typology of different modes of gradual institutional transformations. First, institutions may change through shifts in the relative salience of different institutional arrangements within a given system or, in other words, through a process of successive *displacement*. Second, institutional change may occur through amendments, revisions, or additions to an existing set of institutions, which is called *layering*. Third, existing institutions can be redirected to new goals, functions, or purposes fitting the interests of new actors. This is called *conversion*. Fourth, existing institutions may erode or atrophy as a result of non-decisions and stagnation. In this case, change occurs through *drift*. Finally, institutional change may be characterized by breakdown, collapse, and institutional *exhaustion*.

Specification II: Patterns of sectoral transformation

The concept of gradual transformation as a constitutive pattern of change located in the interstice between overall stability and radical breaks is also useful for analyzing and characterizing processes of technology-based sectoral change.

Of course, historically identifiable leaps of development are always characteristic of major *technological changes* – as with the change to microcomputers at the end of the 1970s, the digitalization of telecommunication infrastructures in the first half of the 1980s, the breakthrough of genetic engineering in the second half of the 1970s, or the introduction of the World Wide Web and the Internet as new information and communication technologies in the second half of the 1990s. Admittedly, such major technological breakthroughs do not result in new and stable technological development paths over the short term. Instead, new cross-sectoral technologies – especially information and communication technologies, biotechnologies or nanotechnologies – are epitomized by a long-running technological dynamic and an often multifunctional and general applicability, which gives them a fluid profile. They are not suddenly complete and ready for service, but are characterized by long periods of research, testing, and reinterpretation, which results in often astonishing and sometimes serious new paths of development, implementation, and application. Beyond very general characterizations – digitalization in information and communication technologies or directed recombination of natural processes in biotechnology – these technology clusters are not characterized by early one-off closures that constitute a new and stable technological standard and development path, but by ongoing technological dynamics, revisions, new openings and sometimes astonishing dead ends (Dolata 2003).

Under these conditions, technological lock-ins and path dependencies are anything but durable and irreversible, as many examples from computer and semiconductor industries, communication technologies, biotechnology or nanotechnology show. "QWERTY," the cipher for a suboptimal but nevertheless persistent standard for typewriters and an often cited paradigm and model of a long-lasting technological path dependency (David 1985), has not yet served its time, though it has lost much of its explanatory value. More typical today are temporary lock-ins, which, as a result of ongoing technological dynamics, are rapidly discarded and replaced by others (Beyer 2006).

This has consequences for the accompanying patterns of *socioeconomic and institutional transformation.* Above all, the permanent advancement of new cross-sectoral or multipurpose technologies puts pressure on the affected sectoral systems and their actors to readapt their structures, institutions, and strategies to new technological opportunities and demands – not just once and in a disruptive fashion, but continuously. Indeed, we can again identify historical leaps or breaks when the established and, for a long time, stable and successful structural and institutional constitutions of given sectoral systems are called into question. For decades the IBM-dominated computer industry, the state-controlled and organized telecommunication sector, the chemically orientated pharmaceutical industry, and the oligopolistically structured music industry were characterized by stable sociotechnical arrangements, which are now being eroded by the advent of paradigmatically new technological opportunities.

However, even where the technology-based pressure to adjust is serious, the patterns of sectoral change are not characterized by short-term and eruptive breaks, followed quickly by a new period of structural, institutional, and organizational continuity. With regard to institutional inertia, on the one hand, even serious sectoral change needs time to occur: the existing structural and institutional arrangements of a sectoral system are not replaced but are renewed successively in the context of search-and-selection processes, fierce competition, and power struggles. On the other hand, ongoing technological dynamics persistently open up new opportunities, problems, and uncertainties; create space for new entrants and first-mover advantages; put the established actors under pressure to permanently renew their strategies and organizational fit; alter existing patterns of competition and collaboration; require the continuous adjustment of legal and regulative frameworks; and evoke changes in societal problem perceptions and patterns of consumption.

Therefore, sectoral change is, as a rule, the result of a multitude of actor-based and gradual transformations successively modifying the organizations, structures, and institutions of a sector – either through endogenous processes, primarily promoted by the actors of the system themselves, or through new, that is to say, system-external actors thronging to the system with strategies of their own. The cited examples show that the modes of gradual transformation as developed by Streeck and Thelen overlap and change over time. Typical of sectoral systems with low adaptability is, first of all, what Streeck and Thelen call drift: an underdeveloped perception of changing technologi-

cal conditions by the established actors and institutions of the system, coupled with a considerable resistance to change. Technology-based sectoral change itself occurs by means of the first three modes: through the successive redefinition of strategies and orientations, collectively shared rules, and guiding principles (conversion); through adjustments to actor constellations, patterns of competition and cooperation, and power relations that were typical until then (displacement); and through the enrichment of existing structures and institutions with new elements (layering).

As a result of such sociotechnical processes of readjustment, the accompanying technological, structural, and institutional changes may be outstanding – however, not as an effect of unique and radical breaks, but as a result of enduring and error-ridden processes of search, selection, and adjustment that often span a number of decades. Their characteristics are

– successive and often error-ridden changes in the strategic orientations, patterns of organization, and guiding principles of the actors and the interorganizational arrangements typical of the sector;
– gradual transformation of the socioeconomic structures of the sector – its industrial structures, patterns of competition and cooperation, modes of production, distribution, and market exchange;
– permanent readjustment of the regulative, normative, and cognitive institutions that function as referees in the games sectoral actors play.

6 Transformative capacity, adaptability, gradual transformation: A framework for analyzing technology-based sectoral change

Together, the three concepts introduced – transformative capacity of new technologies, sectoral adaptability, and gradual transformation – constitute an analytical framework for empirically analyzing and explaining technology-driven sectoral change.

By means of the *concept of transformative capacity*, technology comes into its own as an important factor influencing sectoral change: the concept enables us to identify the technology-driven pressure to change and adjust the existing structural and institutional architectures of sectoral systems.

However, the transformative capacity of new technologies does not lead directly and deterministically to clear-cut structural and institutional logics and modes of transformation. The ways in which the pressure to adjust and change is handled and reflected in new organizational, structural, and institutional arrangements are genuine actor-based processes of search, selection, and readjustment, which are framed by the structures and institutions that exist in each case. So, to obtain the whole picture, the transformative

capacity of new technologies has to be combined with the adaptability of the sectoral structures, institutions, and actors when confronted with the challenges of new technological opportunities. By means of the complementary *concept of sectoral adaptability*, we can identify different modes of sectoral perception and absorption of technological innovation and distinguish different modes of sectoral change.

Finally, by means of the *concept of gradual transformations* we can analyze technology-driven sectoral change, beyond the dichotomy of continuity and sharp breaks, as a multitude of more or less consistent organizational, structural, and institutional readjustments, thereby highlighting the numerous tentative, erratic, and highly competitive sectoral restructurings that span a longer period of time and are typical even of sectors confronted with serious pressure to change.

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