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Opportunities and Obstacles for a Path Change towards Sustainability: The Case of Germany

Diskussionspapier des IÖW 47/00

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Abstract:

A sustainable economy requires a path change of economic development. The political and societal task is a transition to a new path consisting of more environmentally friendly technologies, products and consumption patterns. Technological and social environmentally oriented innovations play a key role in this transition.

However, an analytical approach to meet these challenges has to go beyond the usual economic approach to the topic of environmental innovation that mainly focuses on the appropriate instruments of environmental policy. Instead, the greening of the innovation system has to be put on the agenda.

To explore opportunities and obstacles of such a strategy in a globalised world economy, the empirical part of the paper draws on an analysis of the "greening" of the German innovation system and a sectoral case study of the automobile industry.

Ökologisierung des Innovationssystems? Möglichkeiten und Grenzen eines Pfadwechsels in Richtung Nachhaltigkeit am Beispiel Deutschland - Kurzfassung:

Eine nachhaltige Wirtschaft erfordert einen Pfadwechsel der ökonomischen Entwicklung. Die politische und gesellschaftliche Aufgabe besteht darin, einen Übergang zu einem neuen Pfad zu erreichen, der sich durch umweltfreundlichere Technologien, Produkte und Konsummuster auszeichnet. Technische und soziale Umweltinnovationen spielen für diesen Übergangsprozess eine entscheidende Rolle.

Ein analytischer Ansatz, der diesen Herausforderungen gerecht wird, muss jedoch über den üblichen umweltökonomischen Ansatz hinausgehen, der sich hauptsächlich mit der geeigneten Instrumentierung der Umweltpolitik beschäftigt. Nötig ist vielmehr, die Frage der Ökologisierung des gesamten Innovationssystems in den Mittelpunkt zu rücken.

Um die Möglichkeiten und Grenzen einer solchen Strategie unter den Bedingungen einer globalisierten Weltwirtschaft zu erkunden, besteht der Hauptteil des Diskussionspapiers aus einer empirischen Analyse der Ökologisierung des deutschen Innovationssystems und einer sektoralen Fallstudie der Automobilindustrie.

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1. Introduction

Environmental innovations are increasingly seen as solution to the dilemma of reaching progress towards sustainability in spite of increasing competition on the world market. However, the extent of environmental relief resulting from incremental innovation is often questioned and there are still considerable obstacles for path changing ecologically relevant innovations which might bring more progress towards sustainability. Economic theory, however, has only recently begun to explore environmental innovations in more detail. Environmental economics has mainly analysed the innovative effects of environmental policy instruments while innovation economics has usually neglected the environment. Recent approaches have tried a more integrative view, concluding with a "multi-impuls-hypothesis" (Klemmer et al. 1999). Nevertheless, the starting point of the analysis are regulatory impulses; the same is true for the ongoing IPTS-European research project on the impact of regulation on innovation (Hemmelskamp/ Leone 1999).

We argue that another, somewhat broader starting point could be useful for an exploratory approach trying to capture the whole implications and framework conditions of the desired path changes. A broad approach is necessary which takes the whole innovation system into account. Such an approach has the advantage that it (i) captures the institutional side of innovation, (ii) can take account of innovation dynamics and trajectories with which regulation interacts, and (iii) allows an organic link to questions of the economic and competitive impact of environmental innovation. The latter is important because a change of the development path has to be reached under the conditions of an increased level of competition in a globalised world economy. Nevertheless, the usual innovation system perspective has to be amended by some particularities of environmental innovation, i.e. the importance of regulation in this field (double externality problem, Rennings 2000). Hence a special focus must be laid on the interaction of environmental and technology policy and their interaction with the other actors of the innovation system.

The problem of path changes towards sustainability is thus closely linked to the opportunities and obstacles for the greening of the innovation system. The main objective of this paper is an empirical exploration of these issues, taking the German case as an example. The paper is organised as follows: In the next section, the conceptual approach and its characteristics are introduced. The third section is concerned with an empirical view on the German innovation system and its greening process over the last 25 years. To further clarify questions which can not be answered at a rather aggregate level, the paper is completed by a presentation of the results of a sectoral case study.

2. An innovation system approach to environmental innovation

The concept of a national innovation system emphasises the institutional side of innovation processes, taking explicitly into account the interaction of different actors and the research and development process between science and industry (OECD 1999). In the field of economic theory, the introduction of such a concept marks a break with traditional ways of conceptualising technical change. The role of technical change and innovations has played a prominent role in different approaches of Political Economy but has been neglected with the rise of the neoclassical approach. Technical change has been handled as a black box. Especially in the field of growth theory this category has been used as residual variable explaining the rest of economic growth that could not be explained by the main variables of the neoclassical approach. The work of such an imminent economist as Joseph Schumpeter (1911) with his emphasis of technical change and innovation processes for economic growth and structural transformation has been neglected for a long time. Recently, two streams or research have tried to overcome these deficiencies. While the new growth theory explores possibilities to reintegrate innovation into formal growth theory, economists like Freeman (1987), Lundvall (1988), and Nelson (1993) reinvented some of the Schumpeterian notions in a new framework with some evolutionary undertones: the concept of national innovation systems. With Freeman (1987: 1) we understand a national innovation system (NIS) as "the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies". Any NIS is determined by the time horizon of its actors, the structures of trust embedded in the economy, the mix of forms of rationality, and finally the forms of authority (Lundvall 1998: 409).

The literature is rich with comparative studies of NIS (Anderson et al. 1998, Nelson 1993). Using this concept for the analysis of ecologically relevant innovation and their effects on economic success and international competitiveness is, in contrast, a new field of research. We are following a rather pragmatic approach in trying to integrate the environmental innovation and the NIS debate[1], and ask how ecologically relevant innovations are generated and selected by the national innovation system. Ecologically relevant innovations may be understood as all developments of new ideas, behaviour, products and processes by firms and households which contribute to environmental relief and/ or to achieve some ecologically specified sustainability targets (see Klemmer et al. 1999 for a similar understanding). Using an innovation system framework as starting point, however, implies a focus on technological innovation in industry, i.e. new ideas, products and processes by firms.

2.1. The problem of generating and selecting path changing environmental innovations

The main problem is, under which circumstances path changing innovations are produced and whether they are strong enough to change the overall economic and societal model of development. We argue, that this is related to the selection mechanisms of the innovation system. Whereas the production of ecologically relevant innovations depends on the inner structure and incentive mechanisms of the NIS, the strength of the environmental relief depends on the diffusion power of the NIS.

The conventional neoclassical approach to environmental innovations focuses mainly on incentive mechanisms. Ecologically relevant innovations are such innovations that produce a bundle of positive external economies. As far as such externalities can be appropriated by private actors for free we are confronted with a rationality trap. Economic actors who maximise their private benefits underinvest in innovation efforts that produce positive externalities. This trap is strengthened the more difficult it is to attribute property rights to such externalities. Moreover, environmental innovation is confronted with the well known environmental externalities. Ecol-

[1] For example, there are good arguments to prefer the notion "regime" instead of "system" to avoid the impression that all interactions inside the NIS happen in a purposeful manner (see Hübner/ Bley 1996 for details). However, given that the notion innovation system is more common for the linkages we want to emphasise, we keep to this notion for pragmatic reasons.

ogically relevant innovations face thus a *double externality* problem. In such a case, any market-led economy will produce a sub-optimal amount of those innovations. This leads to the importance of the regulatory framework as key determinant for eco-innovative behaviour of firms and other actors (Rennings 2000: 326). We share this position. Ecologically relevant innovations usually need state assistance and/or a strong and consistent long-term policy framework for economic actors. An innovation system perspective on environmental innovation needs to put more emphasis on state actors than it is common in such approaches.

Nevertheless, the neoclassical focus implies in our view an underestimation of the role of a National Innovation System for any environmental relevant transformation. Especially, radical ecologically relevant innovations that change the product as well as process structure of an economy are confronted with at least three more problems, which can be analysed with a innovation system approach.

(i) Economic processes and innovation dynamics are *embedded in social and technological paradigms* that are reproduced on a day to day base (e.g. Dosi 1982, Hollingsworth/ Boyer 1997). Such processes can show non-ergodic features making them dependent from past events (Arthur 1988, 1989). This kind of path dependency can produce lock-in effects resulting in incremental innovations alongside rather stable pathes that can block any ecologically friendly structural transformation (Linscheidt 1999).

(ii) Economic processes do not happen in an abstract timeless space but are historical processes undertaken by actors. This points to the institutional side of NIS and its importance. This concerns the *interaction* between political actors and scientific and economic actors. Corresponding with technological trajectories chosen in the past we observe the emergence of supporting *actor coalitions* (Nelson 1994). The latter can be powerful enough to block competing innovations, especially in the field of product innovations (Berg 1995).

(iii) Economic processes are never actions within a closed economy but confronted and integrated on a more and more global level. This is reflected by an orientation of NIS at market success. However, in case of environmental innovation market success is often dependent on national regulations. International competition and different regulatory frameworks impact on ecologically relevant innovation processes, an impact which is often supposed as negative[2].

National systems of innovation have to respond to these challenges. Historically, the selection process of innovation systems tends to be biased towards increases in labour productivity. However, sustainability requires a "greening" of innovation systems and thus a change in the filtering process in favour of increases in resource productivity. This goes beyond the typical neoclassical solution, namely the change of relative prices and internalisation of external costs through environmental policy. On the one hand, according to recent research the effectiveness of this solution is mainly limited to the diffusion process (Klemmer et al. 1999). On the other hand, due to the embeddedness of policy into established trajectories and actor constellations, such an internalisation may not be feasible.

The greening of the innovation system, and the success of greening strategies, depends also on the interaction between environmental policy and technology policy, their appropriate match-

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[2] Given this processes, also the importance of "nationality" for NIS can be debated (see already Nelson 1993). Nevertheless there are good arguments that the nation state still matters, and this is particularly true for state action oriented at environmental relief.

ing with the dynamics of the innovation system and the interaction of the different actors in the innovation process, going beyond purely technical innovations. Increasingly, these dynamics are influenced by global competition, and the possible scale of the path change depends on the creation and exploitation of first mover advantages, which allow for microeconomic gains for the pioneers (Porter/ van der Linde 1995). These gains may be based on cost-saving process innovation or, perhaps even more pertinent, on a cutting edge in product innovation or technology leadership. Provided that the general trend is towards sustainability, a NIS orienting at an offensive and front-runner greening process may thus even be most appropriate to secure long term economic success and competitiveness.

2.2. Problems of measuring successful greening of innovation systems

Already measuring of conventional success of national innovation systems is a rather tricky problem. Usually, a lot of different indicators are used (e.g. BMBF 1999). R&D expenditures of firms and of the state are often used, serving as a proxy for institutional change which is difficult to measure in itself. However, one well known problem with this indicator is that input is not the same as output. Therefore other indicators such as patents and trade specialisation are used. Another, more output-oriented indicator is the rate of new products, but besides the definition problem, there is a lack of data time series. Another broad indicator of success which is output-oriented, too, is productivity, conventionally in particular increases in labour productivity. For long term evolution, we think that this indicator may be quite useful, especially with regard to process innovation. Moreover, labour productivity is one important determinant of international competitiveness (Hübner/ Bley 1996). In the short term it has drawbacks, too, for example through the influence of non-innovation factors. Another draw-back may be a temporary dilemma between productivity and path changing product innovation (Abernathy 1978). These innovations may open new markets and thus secure success in the future but due to switching costs at least temporarily reduce labour productivity (increases).

The indicator problem becomes even bigger in the case of greening through ecologically relevant innovations. Two strategies seem to be possible: to start from classic indicators of innovation or to start from environmental indicators. Starting from traditional indicators of innovation brings only limited results. For example, concerning ecologically relevant R&D expenditures, there is a data problem: environment-oriented R&D expenditures of industry are usually not known. And also state expenditures are only partly available. But secondly, there is also some doubt that there is a clear link between environmental innovation and R&D expenditures (Hemmelskamp 1998). For other indicators such as patents and trade specialisation, results are even more disappointing. Finally, even a positive direction of this kind of indicators tells us nothing about the impact on the environment.

Starting from environmental indicators involves also some problems. The environmental problem has many dimensions, therefore aggregation causes problems. And single emissions show only one aspect of the problem. Hence in the last years, the environmental discussion has shifted to input indicators such as energy intensity or resource productivity. Given the additional data problems, often environmental expenditures are used as an indicator, even though it is a response indicator which says nothing about the environmental success. From an innovation perspective, only environmental *investment,* if ever, may give some hints, but these are mainly limited to add-on innovations.

Being situated at the crossroads of both types of indicators, in theory the (rate of) increase of resource productivity seems to be quite an ideal solution. because it links the innovation and environmental perspective. Unfortunately, there is a huge data problem, especially concerning the material part of resource use. Another interesting question is, how such an increase interacts with changes in labour productivity, giving some hints concerning the competitiveness question. There are quite a lot arguments that, if environmental aspects have sufficiently been integrated into the innovation system, with the resulting clean technologies increases of labour and resource productivity can go hand in hand (Porter/ van der Linde 1995). However, this may not always be true if sustainability requires more radical innovation in order to reach high increases in resource productivity.

3. The empirical side: greening of the German innovation system?

3.1. A sketch of the German innovation system

The German innovation system consists of three main actors: government, a large variety of semi-public research institutes and associations, and industry. As in other highly-developed economies, R&D is not performed and financed by the same entities. While the government finances a substantial part of R&D (36,2 per cent in 1997; see BMBF 1998: 372-373), comparatively little is actually carried out in this sector (15,2 per cent). The bulk of research activities is paid for by industry (61,6 per cent) and even more is conducted by companies (67,0 per cent). Universities perform important research functions (17,8 per cent of total R&D), but pay on their own only for 0.3 per cent.

It is notable in the context of a potential greening of the German economy, that the research intensive German innovation system is directed towards advanced (not high-tech) technologies in established sectors. Thereby it reproduces the German economy as a whole in patent and innovation activities: 93,8 per cent of industrial R&D is performed by the dominant sectors such as chemical industry, steel, mechanical engineering, vehicle construction industries and the electrical engineering industry (see Stifterverband für die Deutsche Wissenschaft 1998). This focus limits the options for a fundamental shift of the German economy.

Another characteristic feature of the German innovation system is the existence of a resourceful body of public and semi-public research organisations. The system is based on an elaborate division of labour. The Fraunhofer Society (FhG) concentrates on mid- and short-term applied research, whereas the Max Planck Society (MPG) is directed towards basic and long-term applied research. The Helmholtz Centres (GFEs) conduct research in areas requiring long-term investments and involving high economic risks. Closest to industry is the Federation of Industrial Research Associations (AiF) that supports co-operative research projects that are pre-competitive but application-oriented and mainly oriented towards an entire sector. This system proved both stable and successful until the presence. However, currently it is undergoing a process of re-organisation that is marked by two main events. Firstly, enormous cutbacks in government funding of research led to intensified competition for funds. Secondly, the large-scale evaluation of the research organisations and their output led to a more demand-driven focus of their work. Whether these factors will result in a major revamp of the system or in merely minor modifications is open at the presence.

The vast amount of turnover is concentrated on innovative companies. According to most comprehensive survey of innovation activities in the industrial sector, the Mannheim Innovation panel (Licht/ Stahl 1997, ZEW 1998), 57 per cent of all companies were innovators in 1995. A disproportionate share of 80,8 per cent of total turnover is generated by this type of firms. Indicative of the German innovation system is the type of products with which the turnover is generated. 21,2 per cent emerge out of new or significantly improved products; 18,3 per cent by improved products; and 61,5 per cent by not or slightly improved products. Thus, as in the innovation system in general, incremental improvements rather than break-through innovations are the dominant feature.

There have been opposite trends with respect to innovation activities lately. While more companies conduct innovation activities, on the other hand a shift from investment to current expenditures occurred. Moreover, according to the results of the 1997 innovation panel, 59 per cent of industrial innovation activities were medium-to long-term oriented. At the same time, a shift seems to be taking place towards more market oriented innovation activities.

3.2. Indicators of the greening of the German innovation system

In order to have some rough benchmarks for an empirical assessment of the greening process of the German innovation system covering the past 25 years, we first take a bird's view on relevant indicators. Unfortunately, reliable time series about resource productivity are not yet available, in spite of some recent attempts. Especially concerning materials, calculation is only in its very beginnings (Bleischwitz 1998, Statistisches Bundesamt 1998). Only for energy productivity, there is reliable data which may serve as a rough proxy for resource productivity. Given this state of the art, only a broad set of indicators may shed some light on the greening process of the German innovation system. Table 1 gives an overview which due to data restrictions only covers West Germany between 1970 and 1994. While a general trend is quite clearly observable, there have been quite impressing increases in energy and material productivity, the details show a rather mixed picture.

Obviously, some kind of greening seems to have happened. This positive trend is supported by the development of the state environmental R&D expenditures. However, there are some caveats concerning (i) the extent and (ii) the trend of the greening: Labour productivity in industry still increases faster than energy productivity. And looking at the percentages of environmental R&D and environmental investment, the level of greening is not yet very impressive. Moreover, there are some signs - except R&D expenditures - that the greening process has considerably slowed down or even come to a halt since the beginning of the 90s. An innovation system approach may shed further light on this.

Table 1: Aggregated greening indicators for Western Germany

	1970	1975	1980	1985	1990	1994
labour productivity (1)	88,0	100	113,2	122,1	134,0	143,9
labour productivity per hour in industry (2)	80,5	100	122,5	140,6	163,7	187,1
energy productivity in industry (3)	91,3	100	114,2	134,1	161,9	161,3
material productivity (4)		100	135	190	215	
state environmental R&D expenditure (5)		4,17 %	3,91 %	4,62 %	5,14 %	6,32 %
environmental investment(6)		3,6 %	3,1 %	3,5 %	3,4 %	2,8 %
sulphur dioxide emissions(7)		3,3	3,2	2,4	0,9	0,9

1) GDP per employee in prices of 1991, 2) effective value added per working hour in industry in prices of 1985, 3) net production value per final energy consumption in industry, 4) GDP per total material requirements, 5) federal R&D expenditures in the section environment as percentage of total federal R&D expenditures, data refers to 1976, 81, 86, 91 and 96, 6) as percentage of total investment of state and enterprises, 7) in million tons.

Sources: own calculations based on Bleischwitz (1998), BMBF (1998), BMFT (1979, 1988), Diekmann et al. (1999), Görzig et al. (1994, 1997)

3.3. The institutional side of the greening process

The starting point of the greening of the innovation system (for a detailed analysis see Hübner/ Nill/ Rickert 2000) has been clearly set by *environmental policy* actors. Within only a few years, between 1970 and 1974, and largely drawing on international impulses, the social-liberal coalition created an legal and institutional framework which influences the character of environmental innovation up to today, e.g. the clean air act, two water laws, the environmental agency, the council of experts, to name but a few. It was largely a top-down-approach fuelled very much by the administration, although other actors have been involved in the process. After some years of stagnation, new environmental problems and the emerging environment movement led in the first half of the eighties also the conservative-liberal coalition to continue on the way, e.g. concerning a rather strict regulation of air and car emissions, symbolised by the creation of the ministry of the environment in 1986. Environmental research policy largely played an assisting role and was not integrated with conventional research and technology policy.

The characteristics of the regulatory framework have been: legally based (best available technologies principle), limit value oriented, rather reactive and curative. Being successful in some domains as air and water pollution, mostly a special kind of innovation was triggered, i.e. end of pipe treatment of emissions. At the same time, by this the basis for an "environment industry" was laid.

The nineties where based by the spread of some new ideas like sustainability, often stemming from or triggered by the opposition and non governmental organisations, but few "hard" action from environmental policy actors, with the circular economy law as one exception. Only in the last year, some new impulses were set by the red-green coalition, e.g. eco taxes or concerning renewable energies.

Technology policy actors for a long time played a rather unimportant role in the greening process. An environmental technology policy emerged only slowly in the second half of the eighties, centred around the notion of integrated technologies as opposed to add on technologies which, supported by R&D policy, largely dominated (PT-UST 1994). However, environmental product innovation was almost totally neglected (Angerer et al. 1997), and policy integration in the sense of an infiltration of environmental ideas into the core actors of the innovation system lagged considerably. Only in the last five years, there seems to be a broader orientation towards environmental innovation, while at the same time competitiveness issues are put forward much more strongly. Even if there are now some signs of the integration of environmental aspects into conventional innovation policy, the lack of policy integration is still heavily criticised by non-state actors. This lagging is also visible on the institutional side. Environmental research has been integrated into the big research centres, only few new state supported research institutions have been founded in the process of German unification.

Industrial actors as the second pillar of the innovation system for a long time stayed rather passive, opposing too strict regulation especially if it should act technology enforcing, the debate on unleaded gasoline in the middle of the eighties figures prominently in this respect. In the eighties, the importance of the innovation goal "reducing pollution" increased from 28,6 per cent 1983 to 47 per cent 1990. However, till 1997 it fell again to 38,8 per cent (Adler 1997). The leading role of the state holds especially for process innovation, while environmental product innovation is rather market-lead, green consumerism playing an important role. Concerning the importance accorded to them, cost-reduction regularly advances environmentally oriented product development. But there are significant differences between industries (Cleff/ Rennings 1999). One main carrier of environmental innovation is the environmental industry which profited from the state led greening of the innovation system. Environmental technology is hold typical for the German innovation system, being no high-tech branch but a recombination and incremental development of existing technologies building on well established paths (BMBF 1999). On the other hand, this may be one reason for the with 30 per cent (1994) still minor and even falling percentage of integrated technologies at least as indicated by patent statistics (Hemmelskamp/ Werner 1999).

Actors from *science* largely played a rather passive role in the greening process. The big research institutions which dominate the German research landscape reoriented partly towards environment-oriented research but did not set own priorities. Also the other "big players" were not very proactive, with the FhG sometimes serving as (relative) frontrunner. The universities have been explicitly criticised for their sluggish role, especially in the social sciences (Wissenschaftsrat 1994). The Wissenschaftsrat only evaluated the small and new research institutes very positively. However, in the last five years this picture has begun to change, science in the whole taking a more proactive role. The interaction of the actors and the paths and path changes this interaction produces, however, can be studied more fruitfully on a sectoral level of the innovation system (see section 4).

3.4. Green and competitive? - the international dimension

The traditional debate on environmental innovation and competitiveness is split into two parts. On one side, it is feared that the pressure to adapt to environmental regulation causes high costs and therefore reduces competitiveness. Environmental demands are seen as external to the innovation system, add-on technologies are the most prominent example underlying this rhetoric. On the other side, since the end of the 80s the environment industry - which grounds exactly on this end-of-pipe technology - is seen as one driver of German competitiveness. It is still leading on the European and - until recently - even in the world market. It holds more than 50 per cent of the European patents in this area and still nearly 20% world market share (BMBF 1999). Its RCA is far above average, although decreasing (Maennig/ Missbach 1998, Blacejczak 1993).

But the more interesting question is if an greening of the innovation system as a whole is realistic and what is the scope of it? However, an empirical test is extremely difficult. Even the few empirical assessments of the environmental cost- competitiveness loss hypothesis for Germany usually fail to provide evidence in this direction (Felke 1998, Maennig/ Missbach 1998[3]). And if the possible innovative effects are also taken into account, a test becomes even more difficult. Our own analysis of eight rather representative and export oriented German industrial sectors [4], using energy productivity and environmental investment as indicators to be correlated with changes in revealed comparative advantage, did not provide significant results. The only exception was a negative correlation of changes in environmental investment and RCA in textiles. Robust positive correlations, however, could neither be found at this level of aggregation.

3.5. Obstacles and opportunities - an overall assessment

Summing up, the empirical analysis of the German innovation system shows a mixed picture. A first step towards greening took place in the seventies and was mainly induced by two factors: the establishment of a rather strict environmental policy by state actors and a rather successful technological adaptation by industry to the strongly rising energy and material prices provoked by the oil crisis. However, in this first phase the greening impulses came from outside the traditional innovation system. The opportunity depended on a strong position of environmental policy and favourable supporting impulses by energy prices. The infiltration process was limited, at least in certain respects. The duration of the effectiveness of the impulses was quite astonishing, e.g. for a long time there were only small reactions to the again falling energy prices. Some changes in the selection process of the innovation system have been reached. Yet it was not sufficient for a self-sustained greening and despite some environmental success limited from a path change and innovation perspective. The dominant orientation at available technology rather blocked a propagation of innovative impulses, and the technological solutions were mainly of an end-of-pipe-type.

A second phase, i.e. the second half of the 80s and first half of the 90s, shows rather a stagnation. In the first half, there were new regulations, but of the traditional type and with few implications for the rest of the innovation system. Since the end of the eighties direct impulses of envi-

[3] For chemicals they find a negative correlation. However, we have not been able to reproduce this result with our own statistical tests, working with only slightly modified variables. At least, this may be suggestive for the robustness of this kind of tests.

[4] We selected Iron and Steel, Metals, Chemicals, Textiles, Cars, the Aircraft industry, Electronics, and Mmachinery construction.

ronmental policy became weaker - one reason being the rising fear of losses in competitiveness; R&D-policy only slowly took a more ambitious role, aiming first mainly at clean technologies and only recently also at green products and a circular economy. Its - constantly but slowly growing - material resources to foster this remained nevertheless rather weak and isolated from conventional technology policy. Environmental product innovations which are of key importance for a path change were largely neglected. Moreover, at the institutional level, policy integration remains rather weak. With some time lag, interactions between the different actors and the role of industry, science and consumers became increasingly important in the eighties and the beginning of the nineties - but the latter are only partly able to act as autonomous driving force. And while industry commitment and rate of innovative activity was growing in the 80s, there was also in this respect stagnation in the beginning of the 90s.

Thus it is an open question if we are on the way to a further step to greening the innovation system. The evidence is mixed. Even if environmental aspects have by now far more spread into the innovation system, and many actors have begun to integrate the environmental dimension also into earlier stages of the innovation process, a real sustainable greening cannot be observed yet. Environmental policy impulses have stayed weak and a short-term view on competitiveness still largely dominates the debate. New impulses, e.g. from the side of environmental policy are needed, as even stated in the reports on technological ability of the German economy (BMBF 1999). Some beginnings are visible, e.g. eco-taxes and the support of renewables, but the outreach is open to debate. Some opportunities may emerge from appropriately taking the innovation dynamics into account.

Further empirical investigations show that up to now, a general negative impact on competitiveness cannot be verified at a sectoral level. At this level of aggregation, a significant positive impact cannot be discovered neither, pointing to the limits of this level of analysis. To which extent a lower level of analysis can provide further insight into opportunities and obstacles to path changes and the role of the innovation system in this is explored in the next section.

4. A sectoral case study: zero emission vehicles in the automobile industry

As stated above in section 3.1., the automobile industry is a very important branch of the German Economy as well as a typical representative of the German Innovation System. Moreover, it has some other features which make an analysis particularly interesting:

(i) It is an export oriented industry (the export ratio is well above average), in which innovation is important and at least important segments of the world market are characterised by quality or technology competition. This is backed by two empirical results, namely a rise of labour productivity which is below average and a negative, but insignificant, correlation between labour productivity and revealed comparative advantage. This seems at least to leave some potential for path changes. Moreover, automobile industry is the German industry in which R&D expenditures have been grown the most in the last 20 years, rising from below 2 to over 5 per cent of sales.

(ii) It is nevertheless a rather traditional industry following a well established socio-technological path for which, at least for the American counterpart, the productivity dilemma, i.e. a path of incremental innovation leading to productivity increases but blocking more far reaching innovation, has been already demonstrated empirically (Abernathy 1978).

(iii) It is an industry of which the importance is continually rising from an environmental point of view. Traffic is one key driver of the use of fossil fuels and of greenhouse gas emissions. Thus the existing path becomes more and more problematic. Moreover, the environmental burden is mainly related to the product and its use.

The case study of which some interesting results are reported in the following is based on a literature review (primary as well as secondary literature) and personal interviews with main actors of the innovation process, e.g. DaimlerChrysler, BMW and Volkswagen.

4.1. Some observations concerning the greening of the automotive innovation system

Concerning greening indicators, a first observation is that increases in energy productivity of production are well below industry average between 1973 and 1994. Environmental investment is also below average. However, in this sector, also environmental variables related to product use are important. While traditional air emissions have sunk considerably, CO2 emissions of traffic steadily increase, and fuel consumption as indicator of resource productivity lags behind, i.e. the decrease is rather slow and, due to the introduction of the catalyst in the middle of the 80s, only effective since beginning of the nineties. Industry's expenditures for environmental R&D have risen, but exact data is not available. According to some rough estimate of the manufacturers' association VDA, they reach today 20 per cent of total R&D expenditures.

In general, the greening process has been marked by some particularities. Firstly, environmental policy became only relevant in the 80s. Before that time, there have been considerable impulses from the energy crisis (supported by energy policy), setting a first big question mark at the long time continuation of the well established 100 years old technological paradigm "internal combustion engine", corresponding with "automobilism" as societal paradigm, with the state and its infrastructure policy having been one stabilising agent (Canzler 1997). Quite intense research into alternatives, subsidised by technology policy was a temporary response to this shock. However, this came to a halt because of two reasons: Energy and fuel prices fell again and, due to the beginning dying of the forests, emissions arrived at the top of the political agenda. This greening impulse, which made the catalyst necessary, was massively opposed by industry. It has been put into force against the main actors of the innovation system (which nevertheless adapted very quickly to it) and reversed the incremental technology path towards less consuming gasoline motors.

Ironically, however, this impulse in effect stabilised the technological paradigm because it allowed for quite impressing emission reductions which brought the automobile out of environmental debate. Also other environmental challenges, i.e. extended producer responsibility and take back systems for cars as well as the emerging climate protection debate and demands for a "three-litres-car" do not seem to having challenged the path fundamentally up to now.

Nevertheless, partly in the shadow of the sketched developments, and strongly fuelled by 1990's Californian requirements concerning zero emission cars, the debate about new power trains as path changing innovation emerged again. And particularly one option seems to have won the virtual competition between the potential alternatives and emerges slowly as feasible option: the fuel cell power train. This is used as example to demonstrate in some more detail opportunities and obstacles to path changes, their relation to the German innovation system, and the impact of global competition on ecologically relevant innovations. One caveat should be however noted. In this example there is a strong international dimension and one may read it also as an example for the limits of *national* innovation systems, at least concerning the invention phase. However, as will be shown in the following, in the selection process of innovations, national innovation systems play still a crucial role.

4.2. The selection process by the innovation system - the example fuel cell

The fuel cell changes by the means of a chemical reaction hydrogen and oxygen into water vapour and electricity. A fuel cell combined with an electric motor promises thus threefold environmental relief: at least locally zero emissions, a reduction of carbon dioxide emissions, and a more productive use - or in the long term even substitution - of fossil fuels. Up to now, however, it is only used in prototypes and has not yet been introduced to the market.

The regulatory impulse is important but up to now has been rather weak and diffuse. The main impulse has come from abroad, the Californian Low Emission Vehicle Program from 1990, requiring a percentage of 10 per cent of zero or ultra low emission vehicles to be on the market in 2004. However, the original focus of this regulation had been the market introduction of battery driven electric vehicles. After technical problems with this solution, however, the original market introduction date of 1998 has been pushed back. Nevertheless today it is an important impulse for the development of the fuel cell, setting the stage for a regional pilot market. Thus it is also of high relevance to the German, export-driven car industry, not only because of the Californian market alone but also because of the estimated diffusion aspects. The decisive invention however, namely the application of the fuel cell to mobile uses by the Canadian firm Ballard, has already taken place in the 80s. It was nevertheless influenced by a search process towards alternatives of fossil fuels under the impact of the two oil crises and supported by energy and related research policy (Hild 1998).

Considering German regulatory impulses, there is no direct regulation to be mentioned, yet the long term perspective may have a favourable impact. There is a quite ambitious carbon dioxide reduction goal and there are voluntary agreements in Germany, and recently also in the European Union in which the car industry commits itself to reduce specific emissions 25 per cent until 2005 respectively 2008. The EU agreement corresponds with an average fuel consumption of six litres per producer fleet in 2008, which is quite demanding for upper class car producers. Finally, the steady fuel tax increases introduced with the German eco-tax, are worth mentioning, yet their quantitative importance is up to now limited. The main development impulse in Germany, however, arising from Daimlers NECAR prototype development, has already begun end of the eighties. Moreover, research policy is not very supportive. It does not subsidise the development of powertrain applications (BMBF 1996, p. 228), and the highest yearly amount of federal fuel cell development subsidies was 8,8 million Euro in 1995, which is much less than in the United States (Anonymous 2000).

The innovation dynamics and trajectories are quite typical for radical, path changing innovations (and for the rather incrementally oriented German innovation system). For a long time, most car producers were - and partly still are - tied to the old technological paradigm, resulting in the incremental development of the internal combustion engine as main technological trajectory. The seeds of the alternative paradigm emerged abroad, and Daimler Benz (today: DaimlerChrysler) was the only producer in Germany building of this invention. Having a strong strategic orientation grasping the environmental pressure on upper class vehicles, and the necessary funds as backing, Daimler Benz heavily invested into R&D in order to provide a technological niche which enables a future market introduction of the innovation[5]. The result was rapid technical improvement which demonstrated technical feasibility in prototypes.

The other producers were sceptical and, with the exception of BMW, which pursues another innovation strategy towards zero emission vehicles, kept largely to the old innovation pattern. Nevertheless, recently they reacted and began to explore the fuel cell solution, too. Thus in 1998 all but BMW invested R&D into fuel cell development. Interestingly, also global players like Opel/ General Motors and DaimlerChrysler have their development centre in Germany. But there are other stabilising factors of the old trajectory, namely petroleum refining industry and its heavy influence on fuel infrastructure. The latter is perfectly adapted to the existing path, but needs to change fundamentally in order to support methanol ore even hydrogen powered fuel cell cars. Another stabilising factor are well established consumption patterns (Canzler 1997).

The pattern of *interaction of different actors* of the innovation system is crucial to understand the present situation and its evolution as well as the potential dynamics. In general the German automotive innovation system is characterised by the central role of few main producers acting on a global scale. Each of the producers is in the centre of a net of suppliers which usually still cluster spatially, even if global sourcing gets more important. University research plays a rather important role, too.

The relationship between industry and policy, however, is marked by suspicion, and deeply influenced by the clash concerning the introduction of the catalyst mid of the 80s. In the following, there has been some kind of co-operation, marked by several voluntary agreements, nevertheless being often the result of rather important conflicts. On the side of the regulatory actors, one result is that technology policy plays only a minor role, mainly for basic research, and attempts in this direction are rather regarded with suspicion by industry. Moreover, there is few co-operation between environmental and technology policy. One important actor, the federal environmental agency (Umweltbundesamt), even firmly objects to mobile applications of the fuel cell for reasons to be discussed later (Kolke 1999), being in fact a stabilising factor of the traditional path of the innovation system.

This sketch of the German innovation system contrasts with recent developments in the United States. Concerning the development of the fuel cell, there is an intense co-operation between mains promoters from all sectors of the innovation system, the California Fuel Cell Partnership[6]. In Germany, just recently there have been some co-operative research projects involving relevant but not all German producers, GFE and University partners which are mainly oriented at the systems and infrastructure implications. Moreover there is a co-operation of all three important German led producers, VW, BMW and DaimlerChrysler together with upstream fuel and energy producers - which is a rather new development - trying to choose a few alternative fuels on which infrastructure development should concentrate. The co-operation, however is rather

[5] For a detailed presentation of a concept which considers in detail the steps necessary for the creation of a new technology path, namely strategic niche management, see for example Kemp/ Reinstaller 1999 and Kemp 2000.

[6] This partnership aims at the real life demonstration of the potentials and limits of the fuel cell vehicle and includes the Californian Air Resource Board, a government agency, actors from research institutions, fuel cell producers, a methanol producer, and some car producers, especially DaimlerChrysler and Ford (CARB 2000). Also on a federal level, a new co-operative programme tries to explore new vehicle options.

difficult, because the three follow different competitive strategies. Especially BMW acts as campaigner against the quick fuel cell introduction path involving methanol and promotes an alternative, hydrogen/ combustion engine path.

The *world market dimension* sets different impulses. On one side, the rising competition even in the upper segment of the market reduces profit marges and makes huge development costs more difficult to bear. On the other side, technological competition is still a main characteristic of this segment of the world market, and the fuel cell may be one instrument to demonstrate technology leadership. Moreover, the environmental image is of rising importance and being a fuel cell front runner is instrumental in this respect, too, as Daimler acknowledges. It is expected that a pilot market introduction will diffuse rapidly on a global scale. Nevertheless, the importance depends on political strategies, and mainly of the fact, if there will be a "big push" towards fuel cell application or a very slow and gradual market introduction.

Only in the first case, a front runner orientation of the NIS will possibly have important first mover advantages, although they are not very big (Mannsbart et al. 1999), and probably only for a limited time. Further economic implications, e.g. the final location of R&D and component production, are dependent on the question which region will become the lead market. While research is split between Germany, US and Japan at the moment, with a rising importance of Germany, the component producers up to now are located mainly in the US but are assumed to follow the lead market.

4.3. Opportunities and obstacles for a path changing innovation

The main *obstacles* for the selection of a path changing innovation by the innovation system which result from the German example can be summarised as follows (for details see Nill 2000):

- One obstacle is common to many new technological solutions in their early phases. The innovative solution is still more expensive than the well-known technology at place, and the extent of cost reduction by exploitation of the learning curve is uncertain for the involved actors.
- Another obstacle is also not specific, though in this case of particular big importance: the institutional environment but also complementary technologies, in this case in particular the fuel infrastructure, are well adapted to the solution in place and changes involve rather high switching cost. The fewer extent of this cost is one main reason that the methanol reforming fuel cell is the most probable market introduction strategy even if it has environmental disadvantages compared with the direct hydrogen fuel cell which shall substitute for methanol in the longer term.
- A third obstacle is more case specific. The extent of environmental benefit of the fuel cell strategy is quite debatable. The enounced potential benefits concern mainly the car and its use itself. However, also the environmental impact of alternative fuels has to be included into analysis and here results are less clear. The benefits largely depend upon the possibility of methanol or hydrogen large scale production from renewable energy resources. This seems to be possible, but an applicable solution needs considerable development time and is not expected before 2015. But even if the overall carbon dioxide balance should be positive in comparison with a three litre car, the environmental agency argues that climate protection via fuel cell cars is much to expensive and should be achieved by other means (Kolke 1999).

Another argument is, that fuel cell cars may stabilise automobilism, making alternative strategies relying on less car use more difficult to follow (Petersen/ Diaz-Bone 1998). This obstacle demonstrates the important point that a technologically radical innovation may not be equated with radical environmental relief.

- Another institutional impediment involves energy policy actors. Some agents of the new solution complain that a clear, long term oriented and comprehensive energy strategy is missing in Germany. This would be particularly necessary for progress in the hydrogen solution by a production out of renewables like bio mass (instead of natural gas)
- Consumer acceptance is not sure because the extent of the visible benefits is unclear.

A market introduction seems therefore at the moment to be feasible only in the upper middle class segment. Here, price elasticities are smaller, the additional cost is relatively lower and there may be visible benefits for comfort by producing electricity on board. However, use is also limited concerning the upper bound because if the power requirement is too big (for example in sport cars), the fuel cell becomes much to heavy in weight.

However, there are also some *opportunities* which introduce dynamics into the picture:

- The cost scenarios are quite sensitive concerning rising gasoline taxes (Gossen/ Grahl 1998). Provided that an eco-tax dynamics may continue, and alternative fuels are taxed less or exempted, the path changing innovation may become competitive rather quickly.
- There are signs that provided an initial incentive which brings dynamics also into the infrastructure question is there, a self sustaining innovation dynamics will follow. And the voluntary agreement acts in this way because it urges upper class producers to either enter also the compact class segment or to introduce zero emission vehicles to fulfil their commitment. At least, small incentives seem to be enough to introduce a competing technology dynamics with an environmental orientation without necessarily promoting one specific solution. This may even point to a policy guideline which is more general.
- Finally, such a scenario should at least as second best scenario be also acceptable from an ecological economic point of view because it does not block the other promising option within the car system, namely the three litre vehicle. This option is complementary in lower car segments. Moreover, some important other policy measures which bring environmental relief, i.e. eco-taxes and speed limits, are useful for the promotion of both types of solution because efficiency advantages of fuel cell cars are best in lower velocity areas.

Even though from an environmental point of view more far reaching solutions concerning the whole traffic system are necessary - but unfortunately very difficult to achieve -, there seems to emerge a window of opportunity to reach at least some progress by aptly building on ongoing innovation dynamics.

4. Conclusion

The empirical observations on the German innovation system and the sectoral case-study are of course rather exploratory. Nevertheless some important conclusions emerge from analysis:

- The influence of environmental policy impulses on the greening of the innovation system is limited in extent but rests important. The importance is twofold: On the one hand, it concerns mainly the diffusion phase of innovations, in particular of process innovations. On the other hand, there may be an important influence on long term expectations (and their convergence) of the other actors of the innovation system and thus private R&D.

- An innovation system perspective may be helpful for the development of further regulatory approaches which may be able to set impulses for a path changing greening process. Especially an integration of environmental and technology policy but also strategic and long-term approaches involving all relevant actors may be promising. Nevertheless such an approach is quite difficult to put into practice and implies changes in well established relations between the main actors of the national innovation system. For policy advice, a detailed analysis of the (changes in) relevant sectoral innovation systems is necessary.
- Global competition and the competitiveness argument is not valid to block any ambition towards more ambitious strategies. On one hand, the extent of competitiveness effects is limited and usually does not verify in empirical analysis, on the other hand, there may be also positive market effects though the extent of these may be not as important as the Porter-Hypothesis suggests. Nevertheless, impact on global competition is a factor which has to be taken into account - and an innovation system concept may be a useful starting point.
- One caveat is important: not every environmental relief is marketable, and the environmental relief provided by technological innovation, even if of a more radical kind, is questionable. The fuel cell case is but one example. Thus social and institutional innovations which have been neglected in this analysis for reasons of tractability, are crucial, and also the attitudes and behaviour of individuals as consumers and tax payers.
- In our view, further research needs emerge and go in three directions. More detailed but also more comprehensive studies with an integrative focus are necessary. They should take account of the interaction of policy impulses, innovation dynamics and actor constellations. Secondly, a coherent and comprehensive theoretical framework for eco-innovation is needed to guide further analysis. Finally, suggestions for appropriate, feasible and comprehensive strategies have to be developed which take stock on the rapidly progressing research results.

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