Towards a Theory and Policy of Eco-Innovation - Neoclassical and (Co-)Evolutionary Perspectives

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Abstract

Innovation processes toward sustainable development (eco-innovations) have received increasing attention during the past years. Since existing theoretical and methodological frameworks do not address these problems adequately, research need can be identified to improve our understanding of innovation processes toward sustainability in their different dimensions, complex feedback mechanisms and interrelations. This paper discusses the potential contribution of neoclassical and (co-)evolutionary approaches from environmental and innovation economics to fill this gap. It is argued that both approaches have their merits and limits concerning a theory and policy of eco-innovation. Neoclassical methods are most elaborated to analyze the efficiency of incentive systems which seems to be essential for stimulating innovation. Evolutionary approaches are more appropriate for analyzing long-term technological regime shifts. On this theoretical basis, a crucial question is if innovations toward sustainability can be treated like normal innovations or if a specific theory and policy are needed. Three specialties of eco-innovation are identified: the double externality problem, the regulatory push/pull effect and the increasing importance of social and institutional innovation. While the first two of them are widely ignored in innovation economics, the third is at least not elaborated appropriately. The consideration of these specialties may help to overcome market failure by establishing a specific eco-innovation policy and to avoid a "technology bias" by a broader understanding of innovation. Eco-innovation policy requires close coordination with environmental policy in all innovation phases. Environmental and eco-innovation policy can be regarded as complementarily. However, an environmental policy neglecting the potentially beneficial effects of a specific eco-innovation policy (especially in the invention phase) may lead to excessive economic costs. Due to the specialties of eco-innovation, it seems moreover to be crucial to strengthen the importance of social and institutional innovation in both eco-innovation theory and policy.

Keywords: eco-innovation; innovation theory; co-evolution; double externality; regulatory push/pull effect; social innovation; institutional innovation

1 Introduction

Since the world community committed itself in 1992 in Rio to the principles of sustainable development, it has become more and more clear that sustainability means long-term and far-reaching changes of technologies, infrastructure, life-styles and institutions.
Thus the importance of a better understanding of innovation processes has several reasons:

- The demand for drastic reductions of environmental burdens, e.g., of greenhouse gases, implies that adaptation within existing technologies is not sufficient. Instead, regulation strategies to effect "technology forcing" and/or "technological regime shifts" are needed.
- Secondly, innovation is expected to offset burdens and costs induced by environmental regulations. Secondary benefits of an innovation-friendly environmental policy are often seen in reduced costs, increased competitiveness, creation of new markets for environmentally desirable products and processes, corresponding employment effects etc. Although these aspects have already been emphasized by Porter and van der Linde (1995a), the Porter-hypothesis postulating "innovation offsets" of strict environmental policy is not embedded in economic theory and received with scepticism among mainstream economists (Jaffe and Palmer, 1996; Ulph, 1996).
- New types of vehicles, renewable energy systems or corresponding infrastructure often need at least a decade or more for invention, for adaptation and for diffusion respectively. In total, it is realistic to assume time-scales of half a century and more for major changes in important economic and social sub-systems, like technological regime shifts in energy and transport systems. Thus, in situations far away from the desired equilibrium, the importance of analyzing transition and learning processes moves into the foreground.
- Moreover, many scenarios suppose that long-term sustainability goals can not be met by progress in environmental technology and must be supplemented by corresponding life styles, e.g. through energy saving or changing mobility patterns, and institutional changes (ranging from local networks to global organizations).
- Inventing or adapting environmentally desirable processes or products is already part of every day life for a large majority of firms and thus a field of scientific research. As Cleff and Rennings (1998) have shown in a German industry survey, about 80 percent of all innovating firms have been involved in environmental-friendly innovation projects during the past three years. It is hard to find even a small or medium sized enterprise that has no experience at all with substituting hazardous substances, designing and using eco-efficient products, saving energy, waste and material or reducing emissions. Managing eco-innovation is an increasingly important issue for many firms.
- Finally, innumerable sustainability programs and initiatives have been set up to promote innovative policy responses and corresponding scientific research to improve the understanding of global environmental change and it's relation to economic and social systems. Having this in mind, together with long time-scales, a careful valuation of experiences seems to be crucial to identify key determinants and success factors of innovation processes toward sustainability, i.e. to analyze which experiments succeeded, which failed, why they failed, and in which phase.

Since existing theoretical and methodological frameworks do not address these problems adequately, research need can be identified to improve our understanding of innovation processes toward sustainability in their different dimensions, complex feedback mechanisms and interrelations. Such a framework should be able to give some guidelines about how to analyze these processes in their different characteristics and phases, to identify promising examples as well as bad ones, and to give some idea about their transferability to other contexts.
This paper intends to discuss the potential contribution of neoclassical and (co-)evolutionary approaches from environmental and innovation economics to fill this gap. A crucial question is

whether innovations toward sustainability can be treated as normal innovations or if a specific theory and policy are needed. The paper is organized as follows: Section 2 defines basic terms in the sustainability-innovation-nexus. Sections 3 and 4 describe main economic approaches to analyzing innovation processes and environmental policy, i.e., neoclassical and evolutionary concepts in environmental and innovation economics. Finally, conclusions concerning elements of an economic theory and policy of eco-innovation will be drawn.

2 Defining innovations toward sustainability

2.1 Sustainable development

There is an ongoing debate whether sustainable development can be defined operationally. Some agree (overview in Rennings and Wiggering, 1997), others doubt or deny that it can (Norgaard, 1994; Cary, 1998a; Minsch 1998). Those who doubt or deny understand sustainability more as an heuristic idea, similar to ideas of liberty and justice, guiding and orienting our search rather than predicting its outcome[1].

However, with any of these interpretations of sustainable development at a certain point it is necessary to give a more concrete idea about the direction and problem areas of sustainability. In its environmental report 1998, the German Council of Environmental Advisers identified a consensus on problem areas in seven major sustainability concepts developed by European institutions[2] (Table 1).

insert Table 1

Obviously these problem areas require progress toward certain sustainability targets, which may be different across regions, time-scales, target groups etc. The definition of problem areas and the negotiation of targets can be analyzed and evaluated by scientists, but decisions are made in the political process and should be close to peoples' preferences (Rennings et al., 1998). Some may postulate a "revolution in eco-efficiency" increasing it by the factor 4 (von Weizsaecker et al., 1995) or even factor 10 (Schmidt-Bleek, 1994). Ambitious goals as formulated in the Toronto Resolution for greenhouse gases may be watered down in the political process and lead to modest agreements like those in the Kyoto Protocol. However, in our context only two features of a definition of sustainable development are relevant: that it contains an ecological, economic and social dimension and that even modest sustainability targets, as fixed in the Kyoto Protocol, require substantial innovation.

[1] As Cary (1998a, p.12) writes: "Sustainability is not a fixed ideal, but an evolutionary process of improving the management of systems, through improved understanding and knowledge. Analogous to Darwin's species evolution, the process is non-deterministic with the end point not known in advance."

[2] Six were from Germany (one NGO-report, three from the German environmental protection agency, one from the government and one from a parliamentary commission) and one from the European Commission. However, the problem areas may be different in other contexts and countries. For example, agriculture, forestry and households may be added. Several authors consider population policy as a further central element of a policy of sustainability (Pestel/Radermacher, 1996; Mohr, 1996). But compared with environmental problems this issue is still not well addressed in most sustainability concepts and strategies.

2.2 Innovation

In political and scientific discussions the term “innovation” is interpreted in many different ways. A narrow definition defines innovations as technological novelties. Used in a broader sense, innovations include the first-time application of newly acquired know-how, new methods, or new products. The term can also be expanded to include non-technological innovation, such as changes in firm organization or the design of a product.

In this paper innovation will be understood broadly as a change in the information set that connects inputs and outputs (Stoneman, 1983; Tirole, 1989; OECD, 1992; Hemmelskamp, 1997). Thus process, product and organizational innovations are considered and distinguished as follows:

- Process innovations occur when a given amount of output (goods, services) can be produced with less input.
- Product innovations require improvements to existing goods (or services) or the development of new goods. Product innovations in machinery in one firm are often process innovations in another firm.
- Organizational innovations include, e.g., new forms of management like total quality management.

Innovation is different from invention, which is an idea or a model for a new improved product or process. In an economic sense, an invention becomes an innovation when the improved product or process is first introduced to the market. The third phase is the diffusion phase, when the innovation is used and adopted over time.

2.3 Innovation toward sustainable development

2.3.1 Eco-innovation

The general definition of innovation is neutral concerning the content of change and open in all directions. In contrast, putting emphasis on innovation toward sustainable development is motivated by concern about direction and content of progress. Thus the additional attribute of innovations toward sustainability is that they reduce environmental burdens at least in one item and thus contribute to improving the situation in the problem areas mentioned above. Due to unsolved problems of weighting environmental impacts, a technology reducing air emissions and increasing solid waste should be regarded as innovation toward sustainability, too, until it is clearly discovered as an inferior one.

The interdisciplinary project "Innovation Impacts of Environmental Policy Instruments" (German acronym: FIU)[3] has introduced the term environmental innovation (short: eco-innovation) and defined it very broadly as follows (FIU, 1998):

"Eco-innovations are all measures of relevant actors (firms, politicians, unions, associations, churches, private households) which:

- develop new ideas, behavior, products and processes, apply or introduce them and
- which contribute to a reduction of environmental burdens or to ecologically specified sustainability targets."

[3] The project involved 10 institutes and 11 sub-projects including mainly case studies which were supplemented by model comparisons and a representative German industry survey using the Mannheim Innovation Panel (MIP). FIU was commissioned by the German Ministry of Research and Technology (BMBF) and running from 1996 to 1998.

Eco-innovations can be developed by firms or non-profit organizations, they can be traded on markets or not, their nature can be technological, organizational, social or institutional. The following sections will look more specifically at these distinctions.

2.3.2 Technological and organizational eco-innovation

Technological eco-innovations can be distinguished in curative and preventive technologies. Curative technologies repair damages (e.g. contaminated soils) while preventive technologies try to avoid them. Preventive technologies include integrated and additive technologies (see Figure 1). Additive or end-of-pipe technologies include measures like disposal methods and recycling technologies occurring after the actual production and consumption process. Unlike end-of-pipe solutions, integrated or cleaner technologies directly address the cause of emissions during the production process or at the product level. They comprise all measures leading to a reduction in input materials, energy inputs and emissions during production and consumption. Examples include reducing or replacing environmentally harmful inputs by environmentally friendly inputs (e.g. solvent-free lacquers) and changes to the design of products so that they produce fewer emissions during their use and disposal. Integrated or cleaner technologies are often seen as the main technological challenge paving the road to sustainable development and are therefore preferred to additive or end-of-pipe-solutions (UBA,1997; BMBF, 1997).

Insert Figure 1

Organizational changes are, for example, management instruments at the firm level like eco-audits which are obviously of increasing importance for innovation (Bullinger, Rey and Steinaecker, 1997). Eco-innovations in the service sector become more and more relevant when material products are substituted by less-material intensive services (e.g. demand side management in energy and transport, waste management). Thus, reductions in mobility, energy and material flows can to a certain degree be achieved through new services. This requires new infrastructure and system changes going beyond mere changes of a certain technology (Loske, 1997).

2.3.3 Social eco-innovation

Changes of life-styles and consumer behavior are often defined as social innovations (Scherhorn et al., 1997, p. 16). With regard to eco-innovation, the term sustainable consumption patterns as mentioned in the Rio Convention has received increasing attention.

Any successful innovation, if it is technological, organizational or institutional in its nature, has to mesh with peoples' values and life styles. Television, cars and computers make lives more convenient and comfortable. Nevertheless firms spend large budgets for advertising campaigns to sell these products and to influence people's preferences.

It can be assumed that even greater advertising efforts will be needed for promoting sustainable life styles. Behavioral changes are a prerequisite for switching transport modes towards an increased use of trams, railways, buses or bicycles. These social innovations may go along with better technologies, services and infrastructure. Awareness for tuna caught in a dolphin-friendly way and for tropical timber or bananas planted in a sustainable manner may require less behavioral change than information, a certain willingness to pay and perhaps new institutions and instruments (e.g. labels).

In these cases it may be crucial to identify the main obstacles in the diffusion process of already existing processes and products: institutional barriers, lack of infrastructure, professional marketing, knowledge, quality and comfort or distribution systems may lead to unfavorable cost-benefit-ratios.

2.3.4 Institutional eco-innovation

Progress is often understood simply as innovation in firms, with a strong focus on technological progress. Since many problems of sustainable use of nature and land are not primarily technological questions, this may lead to a “technology bias”. Even more, Norgaard (1994, p. 16) identifies unsustainable development itself as a result “from technology outpacing changes in social organization” and postulates that, within a co-evolutionary paradigm of a sustainable management of economic and ecological systems, “incentives and regulations must evolve with technologies”.

Natural resources can often be characterized as open access regimes, and unsustainable use stems from inappropriate institutional arrangements. Innovative institutional responses to problems of sustainability may range from local networks and agencies (e.g. for water resources of local relevance) to new regimes of global governance (e.g. an institution responsible for global climate and biodiversity issues) and international trade (Rennings et al., 1998; SRU, 1998, pp. 318-334). Innovative institutions include improved decision making through new ways of scientific assessment and public participation. An example of an innovative scientific network on the global level is the Intergovernmental Panel on Climate Change (IPCC), numerous other institutions for public discourse upon environmental and technology impact assessment have been established at the national, regional and local level.

Thus, institutional eco-innovations are often seen as a basic foundation for a policy of sustainability (Freeman, 1992; Minsch, 1997). According to Freeman (1992, p. 191), these institutional arrangements should be accompanied by a reorientation of the world R&D system “so that these environmental objectives were given a high priority in the work of industrial, university and government laboratories. This reorientation would be needed to assure the rate and direction of technical change necessary to achieve the first objective (sustainable development).”

The distinctions between the different kinds of innovations can not be very sharp. Collective actions of households concerning sustainable consumption patterns may be regarded as institutional innovations, and the creation of environmental awareness in firms as social innovation. Different kinds of innovation go hand in hand, or, using the terminology of Norgaard, they co-evolve. Or, as Freeman (1992, p. 124) writes: “Successful action depends on a combination of advances in scientific understanding, appropriate political programs, social reforms and other institutional changes, as well as on the scale and direction of new investment. Organizational and social innovations would always have to accompany any technical innovations and some would have to come first.”

3 Eco-innovation in neoclassical economics

3.1 Environmental and resource economics

3.1.1 Superiority of market-based instruments

If markets were perfect, there would be no need for innovation policy. Prices would give the right signals to firms for optimal investment in R&D and new technologies. Consumer would adapt their behavior to their preferences; transaction costs and surprises could be neglected, and the individuals would optimize social welfare automatically by maximizing their own wellbeing.

However, when market failure occurs, the signals of the invisible hand may be misleading for innovation decisions. If prices do not fully reflect peoples' preferences for certain goods or services, investment will be too low. Market failure can appear as external effect, non-separability, information deficiency and inflexibility. In these cases, the government has to correct market failures. Furthermore, issues of intra- and intergenerational equity are not addressed by markets. Thus a fair initial distribution of property rights is necessary before these rights can be allocated efficiently on markets (Rennings et al., 1998).

From a liberal perspective market-based solutions are preferred to correct market failure as they minimize distortions to the market system (Ewers and Hassel, 1996). Market-based instruments like taxes and tradable permits have also been identified in environmental economics as the environmental policy instruments with the highest dynamic efficiency (innovation efficiency). Their advantage is that they give permanent incentives for further, cost-efficient emissions reductions. By contrast, regulatory regimes driven by technical standards (either in a command-and-control system or in a regime of voluntary agreements in which standards are negotiated between government and industry) are not cost-efficient and the incentives for progress in emission reduction vanish after the standards are met.

The superiority of market-based instruments has been the basic lesson from environmental economics concerning innovation. However, several exceptions and modifications to the rule have been made recently:

- The innovation efficiency of standards can be improved substantially by "technology forcing" in a command-and-control regime (rules of permanent reductions or long-term standards going beyond existing technologies) and by repeated negotiations in a regime of voluntary agreements (continued process of negotiations after each monitoring phase) (Hohmeyer and Koschel, 1995; Brockmann, 1998).
- The innovation efficiency of taxes may be watered down in the political process. Total environmental costs for industry are normally higher under a tax regime than under alternative regimes of command-and-control or negotiated agreements (because firms have to pay for residual emissions and pollution). This may lead to a tendency to impose relatively low taxes with low innovation impacts. It is important to note that it is exactly the innovation-friendly attribute of taxes (charging firms for residual emissions) which may lead to this counter-effect (low tax level with low impacts) (Kemp 1997, p. 64).
- Considering these facts, Kemp (1997, p. 64) summarizes that a regime of free tradable emission permits is preferable with regard to innovation efficiency: "This is because a tradable permit system combines the advantage of a tax system with that of a command-and-control regime: Environmental improvements are achieved at the lowest costs and there is no uncertainty about

the total level of emission reduction." Although Kemp's model includes technological uncertainty and a risk-averse regulatory agency, not all aspects relevant for innovation are considered. Examples are the behavior of interest groups in the political process, transaction costs and distributive consequences. Conclusions may however react sensitively to the introduction of these aspects, e.g. to the consideration of transaction costs in emissions trading systems.

- Further modifications have been derived in general equilibrium models of endogenous growth and in game theoretic models. While the superiority of market-based instruments has been confirmed for situations with perfect competition and full information, the situation may change under imperfect competition. When firms gain "strategic advantages" from innovation, standards may be more appropriate for stimulating innovation (Koschel, 1998).

3.1.2 Perspectives

Aspects that receive little attention in neoclassical studies analyzing the innovation impacts of environmental policy are (Hemmelskamp, 1997; Kemp 1997, pp. 39 - 49):

- The fact that innovations are in most cases not developed by the polluting firm but by specialized firms in the eco-industry. Innovators and polluters may have different incentives and interests. The eco-industry wants to maximize profits and turnover and may be interested in stricter regulation, while the polluting firm wants to reduce avoidance costs and tends to oppose stricter regulation.
- Most studies only analyze market failures due to external costs, only few consider information deficiency and inflexibility. Imperfect knowledge about technological options, surprises and high transaction costs are normally ignored in neoclassical approaches. Ignoring X-inefficiencies, it is for many economists hard to understand that "innovation offsets" of a strict environmental policy - as postulated in the Porter-hypothesis - can occur.
- Problems of implementation and design of pollution control instruments, e.g., stringency, flexibility, differentiation, phasing, enforcement and sanctions, are often ignored.
- Moreover, neoclassical approaches follow a simple, mechanistic stimulus-response model of regulation and neglect the complexity of determinants influencing innovation decision in firms. These determinants will be introduced in the following section of this paper.

Having identified severe drawbacks of neoclassical models of pollution control concerning their relevance for decision-making, it is important to mention some oft their merits. Neoclassical approaches are open to all kinds of eco-innovations, if they are technological, organizational, social or institutional in nature. Due to the norm of consumer-sovereignty, environmental economists do not intend to change peoples' preferences but try to measure them. For a correct measurement of "sustainable preferences", special attention has to be paid to measuring the very long-term utilities of natural goods and services (Chichilnisky, 1998).[4] When supply with environmental services is lower than peoples' revealed demand, institutional and social barriers can be identified to overcome them. For this purposes, institutional approaches have been developed, analyzing the appropriate institutional setting for specific attributes of economic transactions, or the interaction of utility-maximizing groups. Relevant approaches are game theory, theory of public goods, public choice and transaction cost theory. For example, Cary (1998b) has applied transaction cost theory to land management problems in Australia. Due to the attributes of the transaction - low knowledge of the transformation process, low separability of inputs and outputs - he identified relational contracts and cooperation as the most appropriate organizational form. On this theoretical basis he appreciates

[4] An overview of suggestions for considering issues of intra- and intergenerational equity in the measurement of peoples' willingness to pay (equity weighting and adjustment of discount rates) is given in Rennings and Hohmeyer (1998).

recent institutional innovations in Australia towards a more cooperative way of land management. In such a framework, social and institutional eco-innovation can be analyzed from a neoclassical perspective[5].

3.2 Innovation economics

3.2.1 Specialty of eco-innovation I: double externality

While the necessity of environmental policy is not doubted in environmental economics, the necessity of a specific policy (and a corresponding theory) of eco-innovation has to be justified. Against this background, this section puts some emphasis on identifying the specialty of eco-innovation making it different from other innovations.

To start with, eco-innovations differ from normal innovations because they produce a double externality. External benefits (spill-over effects) are quite normal for basic R&D efforts for every kind of innovation. The special character of eco-innovation processes is that they develop products and services which themselves cause external benefits (or: a smaller amount of external costs compared to competing goods and services on the market). In a perfect neoclassical world where all external costs are internalized, the double externality problem would vanish and eco-innovations could be handled like normal ones. Thus, neoclassical economists may only see a necessity for a specific eco-innovation policy, if at all, in a transition phase until a full internalization of external costs is achieved.

But the situation may change when imperfect knowledge, inflexibility, institutional aspects and transaction costs are considered. When innovation policy can cut the costs of environmental protection substantially and thus reduce the overall externalities, this may be more cost-efficient compared to a pure internalization strategy with unknown environmental efficiency (due to obstacles and a watering down of market-based policy instruments in the political process) and uncertain economic consequences (uncertainty of a double dividend[6]).

An example: In Germany many environmentalists (including environmental economists) postulate that fuel prices should rise up to the dimension of 5 Deutschmarks per liter of fuel (around 10 $ per gallon) to internalize external costs and to reach national targets in climate policy. It is argued that this will accelerate the development, market-introduction and diffusion of eco-efficient cars. While this may be true for the innovation and diffusion phase, the preferability of pricing measures on invention is quite uncertain. And a corresponding price shock comparable to the oil crisis may lead to undesired economic side-effects. In this situation, design and speed of the process of change become increasingly important. Giving people and industry time for adjustment to new technologies considering the life cycle of the existing capital stock may cut the costs of a policy of sustainability substantially. Thus a strategy seems to be preferable which:

- is oriented on long term environmental targets,
- does not determine final prices and
- increases prices continuously in small steps until the environmental goal is reached.

An example are the British fuel duties which increase annually by 6 per cent unlimited in time (HM Customs and Excise CE3, 1997). Simultaneously, experiments and learning processes in smaller

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[5] As Cary (1998a, p. 8) writes: „It is likely that the development of a culture of environmental concern and consequent trusting cooperative action will reduce the high ‘transactional‘ costs associated with many land management problems.“

[6] For an overview of the discussion about a double dividend in climate protection see Conrad and Schmidt (1998).

scales may increase the number of policy options and lead to decreasing costs. Innovation policy can stimulate especially the process of invention, reduce undesired economic side-effects and increase the diversity of options, e.g. by supporting the development of eco-efficient cars or pilot projects of coordinated regional and local action improving sustainable mobility. Although learning processes induced by such projects may be slow and more long-term oriented, they can help to save costs on larger scales.

Thus environmental policy and eco-innovation policy can be seen mainly complementarily. Innovation policy can help to cut the costs of technological, institutional and social innovation especially in the phases of invention and market introduction, e.g. by financial support for pilot projects. And in the diffusion phase it may help to improve the performance characteristics of eco-innovations. At least in the diffusion phase, however, coordinated action between environmental and innovation policy seems to be necessary to achieve significant ecological impacts.

Thus, for theoretical and practical reasons, the double externality problem can and should not be solved by environmental policy alone. Nor can it be solved solely by private firms whose R&D investments in eco-innovation can be assumed to be sub-optimal as long as external costs are only partially internalized. In a real world, it is hard to imagine a perfect regulatory framework internalizing all external costs. And even if such a framework would exist, eco-innovation policy would be beneficial due to time lags of the internalization process.

3.2.2 Specialty of eco-innovation II: regulatory push/pull effect

Since both externalities result in a sub-optimal investment in eco-innovations, the double externality problem induces a second specialty: the importance of the regulatory framework as a key determinant for eco-innovative behavior in firms, households and other institutions. The main discussion in innovation economics has been whether technological innovation has been driven by technological development (technology push) or by demand factors (market pull). Empirical evidence has shown that both are relevant (Pavitt 1984). With regard to eco-innovation, new eco-efficient technologies can be subsumed under technology push factors, while preferences for environmentally friendly products or image can be subsumed under market pull factors. Due to the externality problem of eco-innovations, the traditional discussion of innovation economists has to be extended to the influence of the regulatory framework (regulatory push/pull). Figure 2 illustrates the determinants of eco-innovation. As empirical evidence shows (Green et al., 1994; Porter and van der Linde, 1995a, 1995b; Kemp, 1997; Hemmelskamp, 1997; Cleff and Rennings, 1998), the regulatory framework and especially environmental policy have a strong impact on eco-innovation. Eco-innovations are, in contrast to such technologies as microelectronics and telecommunications, normally not self-enforcing. Since factors of technology push and market pull alone do not seem to be strong enough, eco-innovations need specific regulatory support.

Insert Figure 2

Cleff and Rennings (1998) have analyzed determinants of technological/organizational eco-innovative behavior at the firm level considering explicitly different categories of end-of-pipe and cleaner technologies. Empirically the study is based on data from the Mannheim Innovation Panel (MIP)[7] 1996, which had introduced some questions to identify eco-innovators. In an additional telephone survey with these eco-innovative firms, some more specific information has been

[7] The MIP is part of the European Community Innovation Survey (CIS).

gathered. The multivariate analysis shows that within their innovation goals eco-innovative firms attach significantly higher importance to cost reduction and total quality management (TQM) than other innovators. Obviously eco-efficiency is understood as a part of total efficiency. With regard to integrated technologies, differences between ecological product- and process-innovations are identified. Environmental product innovation is significantly driven by the strategic market behavior of firms (market pull effect), while environmental process-innovation is more driven by regulation (regulatory push/pull effect). More specifically, significant regulatory push/pull effects impacts have mainly been measured for "soft" instruments like negotiated agreements, eco-audits and environmental liability law. This result can be explained by:

- the dominance of "soft" respectively missing "hard" instruments in Germany in recent years,
- the absence of market based instruments and the
- experience that effects of direct regulation (command-and-control) may be not significant because they do not discriminate between eco-innovative and non eco-innovative firms.

3.2.3 Perspectives

Using industry micro-data either for technological or organizational innovations, such studies may improve our understanding of short-term, incremental changes in firms. They should be supplemented by additional surveys on eco-innovation in the service sector. With regard to strategies of de-materialization or de-carbonization of consumption and production patterns within a policy of sustainability, innovation in the service sector plays a key role. Since large parts of green production belong to the service sector (e.g. changes in waste treatment, transport and technical consulting), there is a strong need for empirical research in the relevant branches. Surveys should be supplemented by case-studies analyzing the success and failure of interrelated technological, social and institutional eco-innovation.

For long-term innovation processes including more radical changes, however, neoclassical models assuming marginal changes and equilibrium situations may be too narrow. Broader evolutionary approaches have been developed to improve our understanding of radical system changes. Their contribution to a theory and policy of eco-innovation will be discussed in the next section.

4 Eco-innovation in (co-)evolutionary approaches

4.1 Variation, selection and co-evolution

While deterministic neoclassical models have their merits especially for analyzing marginal or incremental changes induced by different kinds of incentives, they are of limited value for the analysis of more radical changes of technological systems including the organizational and societal context. According to Freeman (1992, pp. 77-81), incremental innovations can be characterized as continuous improvements of existing technological systems (i.e. they fit in existing input-output tables) while radical innovations are discontinuous (i.e. they require new lines and columns in input-output-tables).

Evolutionary approaches have therefore been developed to open up the "black box" of surprises being connected with radical changes: unpredictable interactions of sub-systems, irreversibility, path-dependency, lock-in effects of technological trajectories or bifurcation. Evolutionary approaches are more interested in the analysis of transition and learning processes than in equilibrium states, and assume bounded rationality and rules of thumb rather than optimization. Main methods are case studies and ex post analysis since predictions regarding which option will succeed are recognized as being impossible.

The biological terms of selection and variation are used to describe the innovation process. Inventions are variations which succeed or fail in the evolutionary process due to selection criteria of their environment. According to Freeman (1992, pp. 123 - 127), the selection environment of the innovation process can be divided into three categories:

- Natural environment. Man-made environmental problems or external forces may put selective pressure on society to create new technologies, e.g., phasing out CFCs to protect the ozone layer or forcing energy saving technologies to mitigate climate change.
- Built environment. The built environment consists of physical assets, i.e. the existing infrastructure. The built environment needs decades to be depreciated, thus slowing down innovation and diffusion processes.
- Institutional environment. Profitability can be identified as a key selection criterion in market economies.

It should be noted that the variation-selection-terminology focuses only on technological innovations and does not explicitly consider complex feedback mechanisms between variations and the selection environment. This seems to be inadequate having in mind that an innovation is not only selected by the environment but also changes the environment by selective pressures. CFCs have depleted the ozone layer and led to the invention of CFC-substitutes, changes of institutions and consumer behavior. These responses (such as "soft" CFCs) put again selective pressures on the environment raising concern for improved eco-innovations. Similar feedback-mechanisms can be observed in energy policy where eco-innovations such as cleaner fossils, safer nuclear, rational use of energy and renewables are responses to environmental pressures (scarcity of fossil fuels, air pollution, greenhouse effect, nuclear risks) but also change the environment by selective pressures.

In ecological economics, these complex feedback mechanisms have been addressed by the co-evolutionary paradigm as defined by Norgaard (1984, p. 161): “In biology, coevolution refers to an evolutionary process based on reciprocal responses between two interacting species. … The concept can be broadened to encompass any ongoing feedback process between two evolving systems, including social and ecological systems. … Sociosystems and ecosystems are maintained through numerous feedback mechanisms. Coevolution occurs when at least one feedback is changed, which then initiates a reciprocal process of change."

Norgaard and Dixon (1986) have derived some general rules from a co-evolutionary perspective for designing projects which may be applicable to a policy of eco-innovation:

- sustain system productivity and diversity,
- start small and experiment,
- use monitoring and experiental learning systems,
- maintain flexibility,
- reduce vulnerability and
- avoid big, fixed plans.

4.2 Specialty of eco-innovation III: increasing importance of social and institutional innovation

Having in mind the danger of a technology-bias as mentioned in section 0, the co-evolutionary framework seems to be more appropriate to analyze eco-innovations for at least two reasons:

- It includes all sub-systems, i.e. co-evolving social, ecological and institutional systems avoiding any ranking of their importance, and
- it underscores the importance of their interactions.

The history of pesticide policy and the phasing out of CFCs are textbook examples of co-evolutionary innovation processes highlighting the importance of interactions between technological, social and institutional innovations. In the CFC phase-out, the Montreal Protocol has been a key success factor illustrating the importance of institutional innovations (see for details on pesticide policy Norgaard, 1994, pp. 23-28; on the CFC phase-out in Germany and the United States Osorio-Peters and Kuehn, 1998) .

Freeman's emphasis on the crucial role of institutional and social re-organization (cited in section 0) within a paradigm of "green" innovation shows that he is well aware of the need for a broader approach. However, the co-evolutionary approach has not yet been elaborated for specific purposes of eco-innovation research.[8] Thus a research-need can be identified for opening up evolutionary approaches in innovation economics to co-evolving ecological, institutional and technological systems.

4.3 Technological change

Due to the pressures of the selection environment a certain technology may become a dominant "technological paradigm". Advantages in transaction costs, learning curves, economies of scale, superior cost-benefit-ratios and a good fit with existing life-styles, technologies, infrastructures or networks result in path-dependencies or technological trajectories (Dosi, 1988), i.e. to lock-in effects of a technology excluding other evolutionary options. Examples of technological paradigms are oil-based chemistry and semi-conductors.

Kemp (1997, pp. 279 - 289) describes determinants and success factors of technological change as follows:

- Determinants are new scientific insights which open up new technological opportunities, pressing technological needs (e.g., technological bottlenecks to further emission reductions through incremental improvements of end-of-pipe technologies, high costs of further advances within a technical design, such as carbon dioxide reductions within fossil energy technologies, changes in demand, scarcity of materials, or labor conflict) and entrepreneurial activities and institutional support for radically original technologies.
- Important success factors of radical technological change are early market niches and the use of available knowledge and techniques, i.e. a certain compatibility with existing know how, experience and infrastructure.

Having identified these success factors, Kemp (1997, p. 310) suggests to foster technological change by a policy of strategic niche management, i.e., the "creation of protected spaces for promising technologies that we want to point out." The idea is to install temporary pilot markets protected by subsidies or other regulatory measures . Examples are:

- the success stories of wind energy markets in Denmark and Germany which are especially interesting for a close cooperation between environmental and eco-innovation policy, i.e. between economic incentives (subsidies in Germany, energy tax in Denmark) and technology support programs (Hemmelskamp, 1998),

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[8] Although Kemp (1997, p. 3 and p. 276) uses the term co-evolution, he does not explain or elaborate this terminology and concentrates on technological innovations.

- the "Los Angeles Initiative" requiring that zero-emission cars must account for 2 per cent to 10 per cent of new car production in the 1998 - 2003 period as creating a temporary protected area for electric vehicles (Templin, 1991, p. 310),
- the idea of a “Renewables Portfolio Standard” under which every retail power supplier would be required to purchase renewable energy credits equivalent to some percentage of its total energy sales (Rader and Norgaard, 1996).

The examples show that a policy fostering technological eco-innovations can not be reduced to technological support programs nor to conventional environmental policy measures, but has to find intelligent combinations of both. The problem is of course to find a balance between protection and selection pressure. However some protection may be necessary even in the diffusion phase due to the degree of existing external costs not yet internalized by environmental policy. Thus close coordination between environmental policy and eco-innovation policy will be necessary.

4.4 Perspectives

Evolutionary approaches seem to be very useful for providing additional insight into radical technological change. Compared to neoclassical economics they follow a somewhat broader approach as they allow surprises and consider technological path-dependencies. It would be worthwhile, however, to open up the evolutionary framework to ecological irreversibility and to strengthen social and institutional innovations. This may be helpful for avoiding "technology bias."

It seems to be beneficial to link neoclassical and evolutionary models in further research. For example, Kemp (1997) has combined neoclassical and evolutionary approaches of eco-innovation to a certain extent. He introduced uncertainty, specific technology characteristics and shifting consumer preferences into neoclassical models and rational choice and optimization into the discussion of technological regime shifts.

5 Conclusions

Both neoclassical and (co)-evolutionary approaches have their merits and limits concerning a theory and policy of eco-innovation. Neoclassical methods are most elaborated to analyze the efficiency of incentive systems which seems to be essential for stimulating innovation. Furthermore, neoclassical approaches explain two important specialties of eco-innovation: the double externality problem and the regulatory push/pull effect.

Evolutionary approaches are more appropriate for analyzing long-term, radical technological changes including path-dependencies, technological irreversibility, transition processes, discontinuous and unpredictable events. It is suggested here to open up the evolutionary framework to interactions with ecological systems (e.g., to consider ecological irreversibility as a main driving force for eco-innovation) and to strengthen the importance of social and institutional innovations. The co-evolutionary approach has been applied to explain the third specialty of eco-innovation emphasizing these interactions of ecological, social and institutional systems. This underscores the need for a consideration of social and institutional innovation in both eco-innovation theory and policy and may help to avoid a "technology bias".

It can be concluded that the three specialties of eco-innovation require a specific eco-innovation theory and policy. The double externality problem consolidates elements of environmental and innovation theory. The regulatory-push/pull hypothesis is supported by empirical evidence from series of case studies and (fewer) industry surveys. And the relative importance of institutional and social change is mentioned throughout the literature on eco-innovation.

However, the theoretical and empirical work on eco-innovation is still in its beginning. Nevertheless, it seems that it can already give some theoretical support and empirical evidence to establish a specific eco-innovation policy. A carefully designed, forward-looking eco-innovation policy may be able to cut the costs of a policy toward sustainability dramatically. It requires close coordination with environmental policy in all innovation phases. Environmental and eco-innovation policy can be regarded as complementarily. However, an environmental policy neglecting the potentially beneficial effects of a specific eco-innovation policy (especially in the invention phase) may lead to excessive economic costs.

Thus the need for a specific theory and policy of eco-innovation seems evident. Some may wonder if it makes sense to redefine every kind of technical, institutional and socioeconomic *change* or reform as *innovation*. However, in our context the only relevant criteria for valuing change is that it is somehow new and a certain likelihood that it leads in the desired direction. A more restrictive selection and support of options, e.g., a focus on technologies, is explicitly not intended as long as a diversity of other options exists which might be supplementary, superior, etc. Thus innovation policy *should* open up a narrow technological definition of innovation to all kinds of organizational, behavioral and institutional change. This may have quite substantial impacts on avoiding a technology bias and unsustainable development.

Some further elements of eco-innovation theory and policy have not yet been mentioned or elaborated in this paper. They include management approaches in business administration (management of eco-innovation as outlined, e.g., by Porter and van der Linde 1995b; Fuzzler 1996) and approaches from policy analysis (see Blazejczak et al. 1998). However, within a broader co-evolutionary paradigm, conceptual and methodological pluralism and interdisciplinary research are welcome. Approaches from business administration, policy analysis and other disciplines enrich the discussion. Synergies, conflicts and complementarity between the concepts may be an issue for further research.

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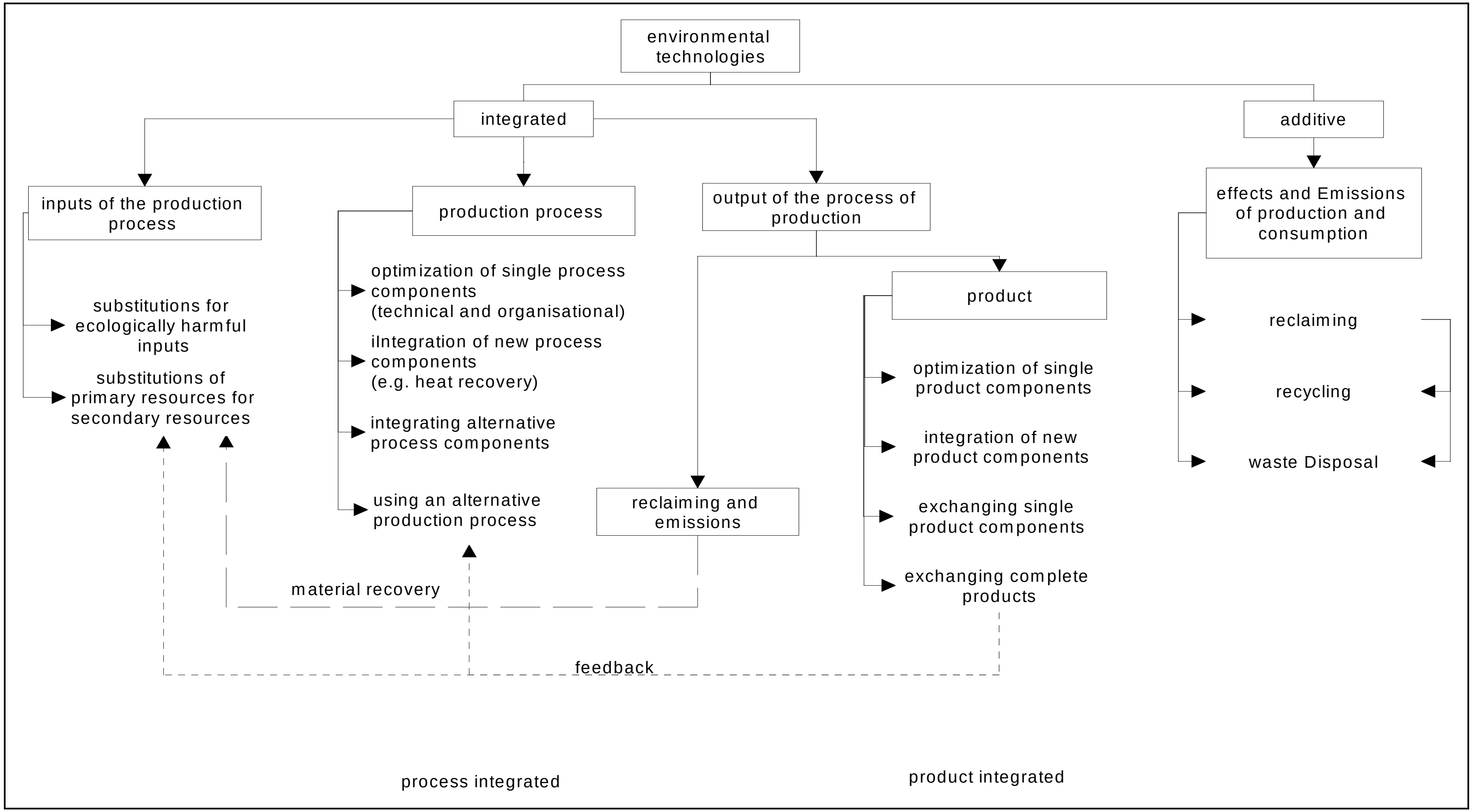
Table 1: Common areas of problems and sectors addressed in sustainability concepts

Main problem areas	Main sectors
Greenhouse effect Depletion ozone layer Acidification Eutrophication Toxic impacts on media/ecosystems Toxic impacts on humans Loss of biodiversity Use of soil, land Resource use	Energy Mobility Waste

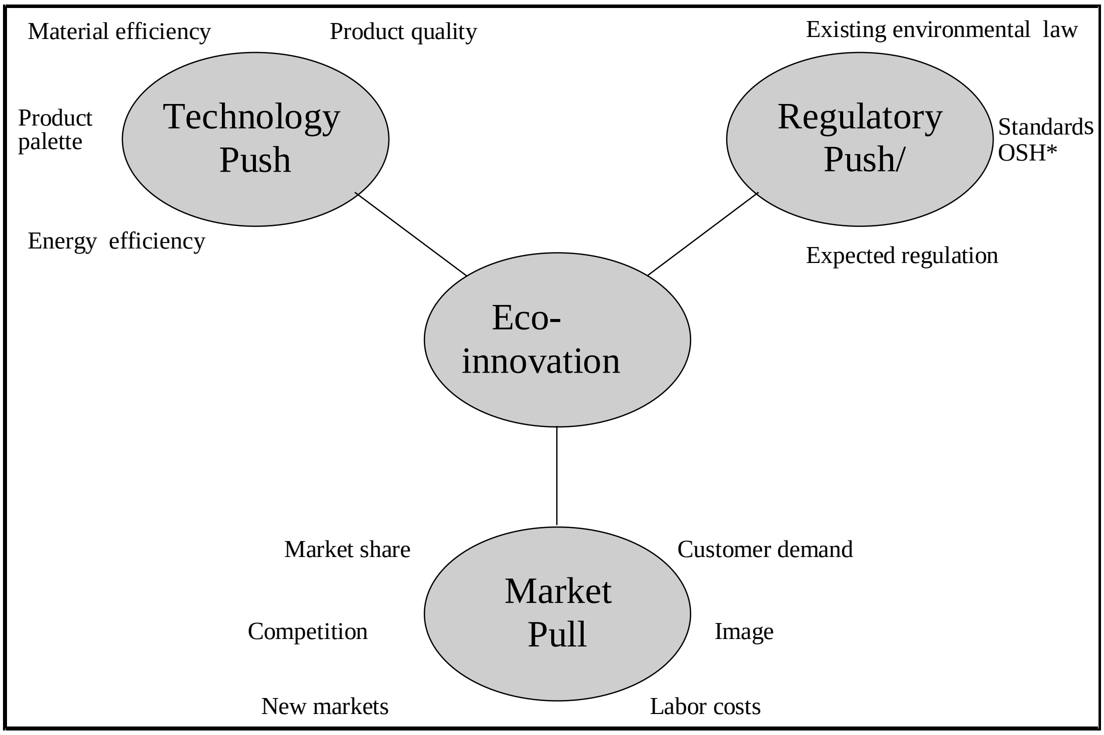
Source: SRU (1998), p. 88.

Figure 1: Overview of preventive environmental technologies



Source: HOHMEYER / KOSCHEL (1995, 6).

Figure 2: Determinants of eco-innovations



*OSH = Occupational Safety and Health