Knowledge and Environment

Innovation for Sustainable Development

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1 Introduction

Knowledge plays a key role when it comes to reducing the materials intensity ("scale") of the economy, a goal that is beyond the reach of conventional environmental policy. Our main argument is that the knowledge problems of conventional environmental policy cannot be resolved due to the enormous complexity and the inherent dynamism of both ecosystems and economies. At the same time, there are reasons to believe that a reduction in the overall scale of industrial production and consumption are unavoidable in order to assure sustainability. We suggest that the MIPS concept which tries to grasp the materials intensity of the economy is useful as it opens new scope for utilizing the information- and knowledge-creating function of market processes. MIPS stands for material intensity per unit of service and represents a new way of looking at environmental issues. It is related to the factor 10 goal as suggested by the Wuppertal Institute: reduce the material flows through industrialized economies by 90 %. We explain this concept in section 2.

In section 3 and 4, we address the relationship between knowledge and environment with regard to the micro- and the macro-level:

– We address the categories of incremental vs. radical technical change, learning, path dependence, and trajectories in the context of conventional environmental policy. The point of departure in this context is the assertion that knowledge and technical change are closely related concepts. The main argument is that, because of the existence of trajectories, path dependence, and the conceptualization of technical change as a cumulative process, it is not surprising that even conventional environmental policy has often stimulated innovations that in the end turned out to both improve competitiveness and the environmental performance.

– At the macro-level, we argue that a profound structural change will be necessary to achieve sustainability. The MIPS concept provides useful instruments to stimulate such change. Furthermore, we argue that innovation and knowledge play a key role. We introduce the concept of path policy to point out that the latitude to shape industrial development changes profoundly in the course of innovation cycles, being relative large in the initial phase when a technological trajectory is not yet clearly defined but rapidly becomes smaller as soon as this has happened.

In the final section we draw a number of conclusions for the theoretical and conceptual discussion.

2 Knowledge and reducing "scale" – the problem of double complexity

Environmental policy today is increasingly discussed in the perspective of sustainable development: we are talking about the behavior of global eco-systems such as the world climate, biodiversity and carrying capacity. Here we face a double problem of complexity (Hinterberger/Luks/Stewen, 1996): both ecological and socio-economic systems are highly complex and evolve in a largely unpredictable way, which makes a direct control of environmental damage difficult. As we lack full insight into the complexity of ecological systems, we are (and always will be) unable to draft a comprehensive list of all economic activities contributing to the deterioration of the ecosphere. Extrapolating from this experience we can exclude the possibility that we might ever obtain full information on the most relevant ecological impacts in the future. Due to the complex character of the ecosphere cause-effect relationships depend heavily on time paths and singular antecedent conditions. Hence, every reaction of the ecosphere to human interference has to be experienced anew and is essentially unpredictable. Knowledge of environmental deterioration is therefore necessarily limited and subject to constant change (Hinterberger/Wegner 1997). Looking at the history of environmental policy, we can identify a pattern: Whenever the damage caused by a given substance was identified, production and consumption moved to some substitute. Then the substitute's potential to cause environmental harm was identified, and the cycle started again, etc. etc.; SO_2 was followed by NO_x, CFCs, and CO_2 as the main target for emission control. This kind of environmental policy is inefficient, and it does nothing to establish a sustainable pattern of development.

Environmental policy needs a comprehensive indicator of environmental disruption instead. Energy is such a comprehensive measure, which covers many human-made influences on nature. But it is not only the use of energy but that of any resource that in one way or the other disturbs equilibrating ecological processes. Not only emissions, but already the material input into the economy (including excavations, derouted water and the use of renewable resources) has an ecological impact.

Material flows are a measure for what Herman Daly (1991) terms the "scale" of an economy. Various authors argue convincingly that global material flows per year should be reduced by about 50 % over the next 30 to 50 years (Schmidt-Bleek 1994, Adriaanse et al 1997, Hinterberger/Luks/Schmidt-Bleek 1997, Luks 1998). To allow developing economies which today use comparatively few ressources to grow, we suggest a reduction for industrialized economies by a factor of 10. This factor of 10 (or about 5 % per year) is meant to apply for entire economies and not for single products (see Schmidt-Bleek 1994).

The MIPS concept was introduced by the Wuppertal Institute as a comprehensive measure of material flows, a measure than can be used to monitor progress toward sustainability. It can also be used to design the optimal eco-efficiency of goods and infrastructures. The goal is in all cases to reap as many units of service as possible from each "service delivery machine" for as little material (and low material intensive energy) input as necessary. This equally holds for mouse-traps, cars, and railroad infrastructures during the manufacturing phase and through the use cycles (maintenance, operation, cleaning, repair, collection, sorting, re-manufacturing, recycling etc.). In all phases, transportation and packaging intensities need be considered (see Box 1).

MIPS provides an instrument that can be used to reduce the ecological burden by using market instruments. The method for material intensity analysis can be applied for micro as well as macro levels. It has been used to include environmental considerations into national accounts and for monitoring overall progress toward sustainability (see Box 2) as well as for sectoral input-output studies (see Hinterberger/Moll/Femia, 1997).

Box 1: The MIPS Concept

The **resource productivity** can be defined as the amount of use (or service) associated with, or derived from, a given amount of energy and material-and with reference to the total life cycle of industrial and agrucultural products that fulfil services to consumers (Schmidt-Bleek 1994, Schmidt-Bleek et al 1998). In so doing, each raw material, intermediate, or end product that is employed is paired with an "ecological rucksack," consisting of the weighted sum of all matter and energy used for its production-from cradle to grave. In this manner the environmental quality (associated with the resource effort) of functionally equivalent goods or production sites can be compared directly (Schmidt-Bleek 1996). Whatever knowledge about the human- or eco-toxicity of materials involved that is available has to be included in all decision making processes, something that is generally already required by law (see figure).

The inverse of the resource productivity is the **material input per service unit, or MIPS**. The material input (including energy and transport intensities) reflects all the material displaced with the help of technology in nature in either kg or t, and with reference to a service provided. An example would be the sum total of all resources which were afforded on a life cycle wide basis for a person-kilometer in an automobile.

The material input is summarized in five different statistical categories:

- **abiotic raw materials**
- **biotic raw materials**
- **earth movements in forestry and agriculture**
- **water, and**
- **air.**

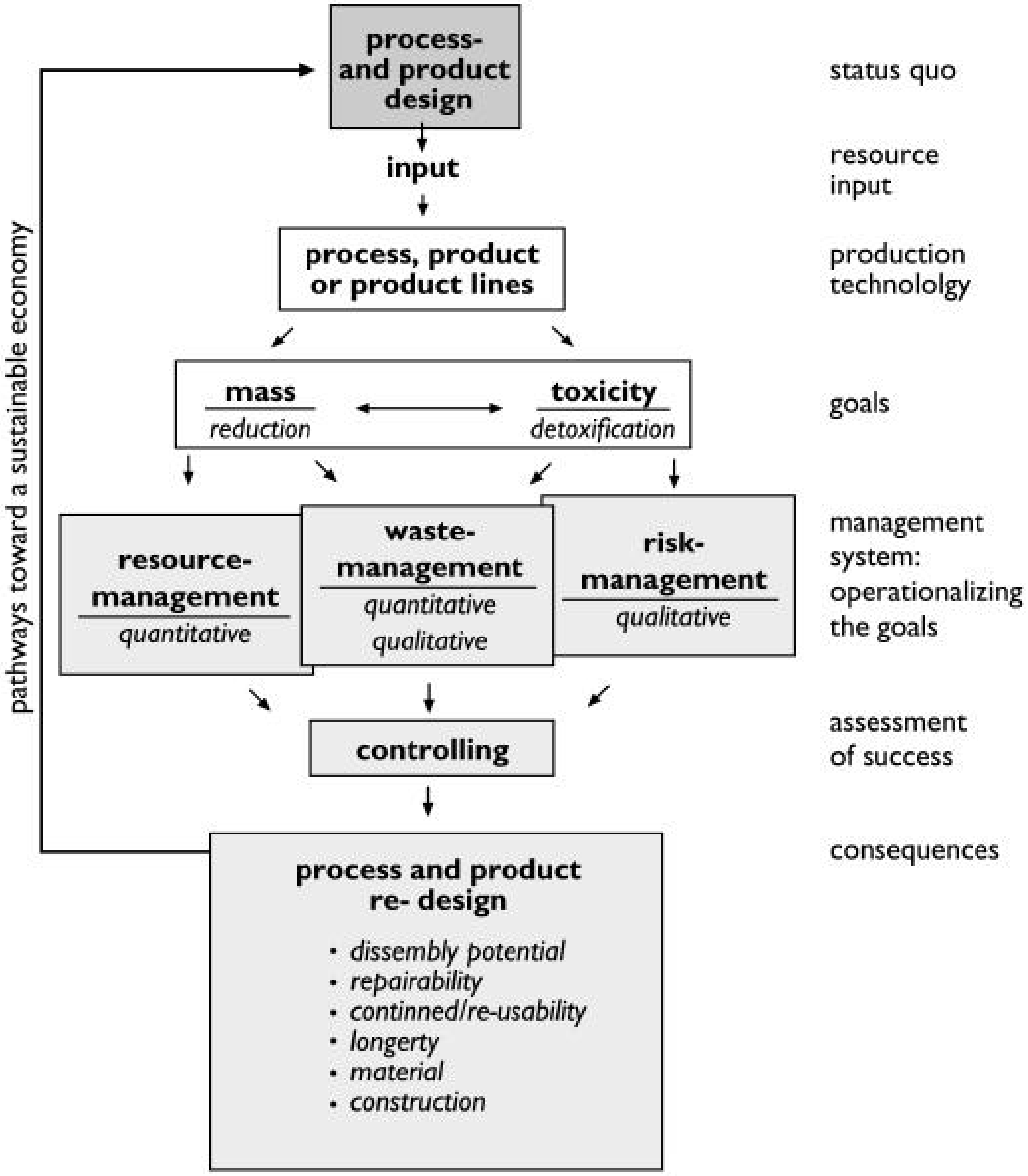
The **material intensity** in each respective category contains the material or resource input per t of material or specific product weight. Seven tons of abiotic raw materials, for instance, per t of sheet steel, or 88 t abiotic raw materials per 110 kV reinforced concrete power pole(see Merten et al 1995) The **ecological rucksack**, on the other hand, represents the resource consumption without the tare weight of the material or product in question. In the case of the sheet steel, ($MI_{\text{abiotic raw materials}}$ = 7t/t) the ecological rucksack of abiotic raw materials weighs 6 t (7 t abiotic resource consumption minus 1 t tareweight).

MIPS can be used to compare durable and less durable goods and to examine complex facilities and infrastructures. With the help of the indicator "resource productivity" it is possible to identify sustainable market niches for materials and products. In this context the term sustainable denotes a marriage between what is economically feasible and ecologically necessary.

(continued)

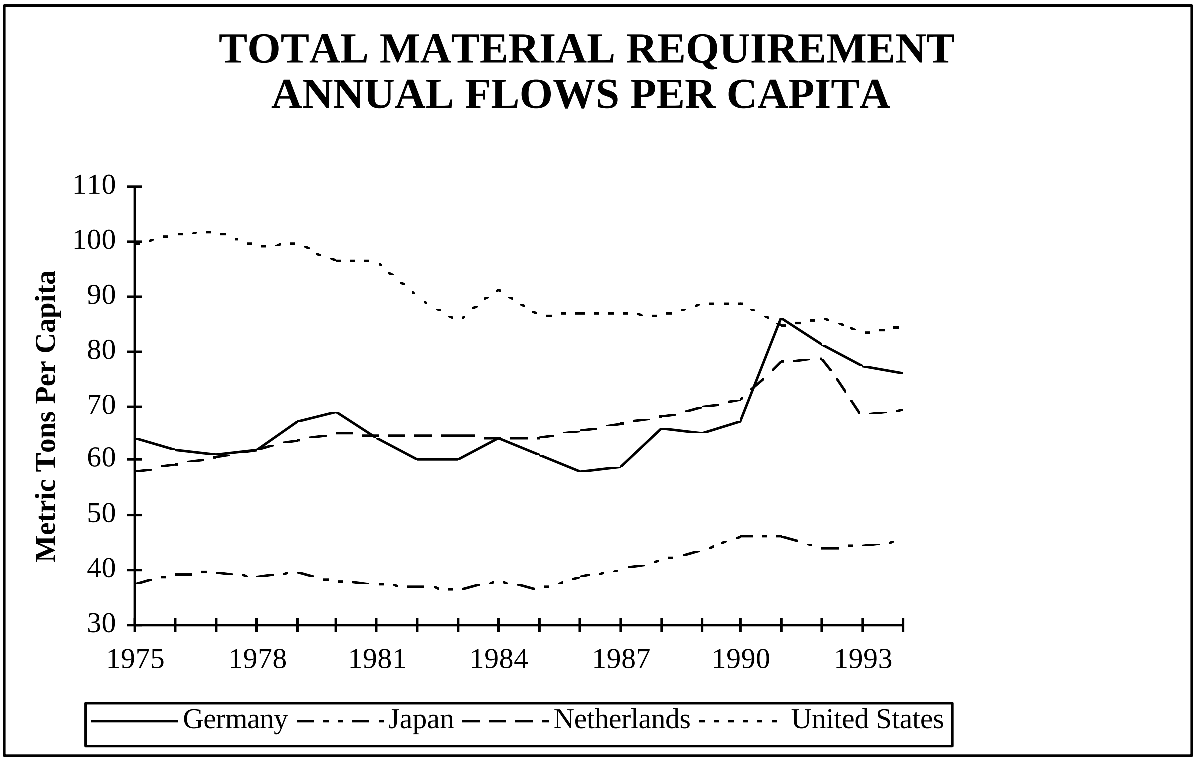
Box 1 (continued)

Fig. 1: Integration of the discoveries from resource, waste and risk management into an environmentally sound process and product design (Schmidt-Bleek/Liedtke 1995)



Box 2: Resource Flows in International Comparison

In a joint study by the Wuppertal Institute, the World Resources Institute, the Duch Ministry for the Environment and the Japanese Institute for Environmental Studies(Adriaanse et al. 1997), the Material Intensity of four industrial economies was examined and expressed as Total Material Requirement (TMR) per capita to point out and to compare the degree and trend of natural resource use on the national levels. Starting from 1975, the TMR per capita varied considerably, but over time the trends converge. In Germany, the Netherlands and the United States, per capita natural resource use appears to be leveling off at about 75 to 85 tons per year. The decline in U.S. TMR per capita in the first third of the period was due primarily to major reductions in soil erosion after the enactment of the Conservation Reserve Program (farmers were paid for not farming highly erodible lands) and the completion of much of the federal interstate highway system. The TMR per capita of Japan showed a slightly rising trend, similar to that of Germany and the Netherlands, but at significantly lower levels, about 45 metric tons per year. The sharp rise in German TMR in 1991 reflects the reunification with the former East Germany; the trend in West Germany had been relatively constant until then.



3 The micro-level perspective: Incremental technical change, learning, path dependence, trajectories, and environmental policy

At the end of this section we will address the applicability of the MIPS concept at the micro-level. Before doing that, we will look at the interrelationship between technical change and environmental issues. It is useful to start with the argument put forward by Porter and Linde (1995) that environmental regulation does not necessarily reduce the competitiveness of firms but can actually free potentials to raise efficiency. This finding is by no means surprising if one addresses it from an innovation economics perspective. The important categories in this context are the observation that technical change is a process, that it is largely based on interactive, cumulative learning, and the observation that technical change is path dependent and follows trajectories.

3.1 Innovation as a process

Freeman (1987, 60ff) distinguishes four types of technological change:

- everyday, *"incremental" technical change* in small steps – an improvement in a production process, an improved product, a new service. It is this type of innovation that ensures that the productivity of firms will grow. Yet it does have inherent limits: even continuous improvements were, for instance, unable to prevent the replacement of sailing ships by steam ships;
- *radical change* due to radical innovations, which alter the course of development of an entire industry – the introduction of the zipper, nuclear technology, or electronic word-processing systems would be examples;
- *changes in a technological system* that affect more than one industry; one example would be the success of plastics;
- *changes in a techno-economic paradigm* – new technologies prevail throughout entire societies, new industries emerge, old industries lose significance, conventional organizational patterns are invalidated. This type proceeds from the theory of long waves.

The first important point is that innovations are in general not sporadic sensations; instead, they have a process character. Incremental innovations – at least in developed capitalist industrial societies – are part and parcel of the essence of industrial production. Firms do not simply remain at a productivity level once achieved. They engage in constant efforts to improve their production processes and products. The most important incentive is provided by economic competition, for if a firm neglects to innovate or fails to innovate sufficiently, it will be unable to assert itself against its competitors.

The process character of innovation puts to the question the conventional distinction of invention, innovation, and diffusion that goes back to Schumpeter. Schumpeter underlined discontinuous *"recombination"* (Schumpeter 1964, 100) (i.e., in Freeman's diction: radical innovation) by the dynamic entrepreneur as the dynamic factor, but

> *"most of the productivity gains associated with the diffusion of new technology do not come as an immediate consequence of the first radical innovation. On the contrary, they usually are only achieved as a result of a fairly prolonged process of learning, of improving, scaling up and altering the new products and processes. This involves many follow-through inventions and innovations throughout the commercial life of the product or system."* (Freeman 1991, S. 305)

3.2 Innovation through cumulative learning

The second important point is this: Since only a steady flow of minor and major improvements, i.e. incremental technical change, leads to the realization of the full potential of a given technology, it does not economically make sense to constantly switch between technologies. Rather, it is economically rational to stick to a given technology so that a cumulative learning process can take place. This learning process usually turns out to be the result of an interactive process. There exists in firms an interactive process between R&D personnel, engineers, technicians and production workers, and marketing and service people. Beyond the boundaries of the firm, customers, competing or cooperating firms, and technology institutions and other research facilities may be tied into this interactive learning process. Such a cumulative learning process will often give rise to increasing returns, i.e. as more people (e.g. researchers and engineers in various firms) start to work on improving a given technology, the rate of improvement grows at the same or even a faster pace than the number of hours that people work on the technology.

These learning processes are not something trivial that will take place in any case. They are actively stimulated and fostered in efficient firms. Technological learning is a complex, protracted process that cannot be substituted for by formalized training over a limited period of time. The reason for this is that technological know-how is never completely tangible and cannot entirely be formalized; a large portion is tacit. Dosi illustrates the term as follows: *"tacitness refers to those elements of knowledge, insight and so on, that individuals have which are ill-defined, uncodified and unpublished, which they themselves cannot fully express and which differ from person to person, but which may to some significant degree be shared by collaborators and colleagues who have a common experience*." (Dosi 1988, 1126)

This leads to the recognition that the perfect information about technology assumed by orthodox neoclassical economics cannot, in practice, exist. What needs to be distinguished here is not merely public and proprietary knowledge. Even if all firms were prepared to hand over their know-how and provide a gigantic information system with data on their stocks of know-how, there would still remain the sphere of tacit knowledge that cannot simply be transferred and is thus not negotiable; and the significance of intangible know-how as opposed to formalizable and negotiable know-how is anything but marginal.

3.3 Innovation, learning, trajectories, and path dependence

Both the cumulativeness and the tacitness of technology and technical change explain the fact that technologies develop in corridors; Dosi (Dosi 1982) coined for this the term ‘trajectory’. Technological trajectories are defined by shared views and shared search patterns.

There is an economic and a technological rationality for the emergence of technological trajectories. On the one hand, firms, owing to the costs associated with learning processes, are interested in preventing their accumulated technological know-how and their technical hardware from losing their value due to radical upheavals (Kemp and Soete 1992, 445). Moreover, the existence of a technological trajectory reduces uncertainty. Dosi argues that the uncertainty associated with innovation is much greater than is assumed in most economic models: *"It involves not only lack of knowledge of the precise cost and outcomes of different alternatives, but also often lack of knowledge of what the alternatives are."* (Dosi 1988, 1134)

On the other hand, there is a close link between the definition of a trajectory and successful innovation. The relative security of a technological trajectory stimulates incremental innovations that are essential to developing the productivity potential of a technology. The reason is the cumulative character of technology, i.e. the significance of the continuous accumulation of know-how.

Technological trajectories narrow down over the course of time, in that a canonization of approaches and views occurs (norms and standardization, textbook knowledge, sunk investment in firms). It is not seldom that a shared view includes shared prejudices on the part of the engineers concerned as to what the market requires (Dosi 1988, 112).

In contrast to widespread notions, decisions concerning a technological trajectory rarely follow a pure economic or technical rationality. Decisions in favor of a given technological line of development, and against others, are based on economic, technical, and political interests, and the outcome often has a chance character. Typically, such a decision is made long before the potential and the risks, the costs and benefits of a technology are clearly perceivable. *"In many cases, a technology is not chosen because it is efficient, but becomes efficient because it has been chosen"* (OECD 1992, 41; Nelson 1992b, 5ff), i.e. it develops superior quality or productivity because development efforts are focused on it, thus generating cumulative learning effects.

The emergence of technological trajectories is associated with discrimination of technical alternatives and the development of resistance against radical innovations (OECD 1992, 40), at least for a certain period of time (which may be decades in the case of complex technologies). When ever greater efforts generate no more than minimal improvements, it is not rare for a technological trajectory to turn out to be a dead-end street for the firms in it. In this situation the conditions for the introduction of a new, radically different and potentially much better technology are favorable. Established firms often have great difficulties switching over to the new technology. The barriers to entry then sink drastically, i.e. the probability grows that firms with radical innovations will move into a market, forcing established firms out of it; the Swiss clock industry and the German typewriter industry are two instructive illustrations of this phenomenon in recent industrial history.

A related notion is path dependence. Path dependent development occurs because it is not sensible for agents to consider all possible alternatives all the time. If a firm has embarked on a given development path it will most likely remain there in order to be able to run through the cumulative learning process which leads to mastery of a given technology. For instance, a passenger car manufacturer will not reconsider its choice of basic concepts (front vs. rear drive, carburetor vs. electronic fuel injection, Otto vs. Diesel vs. Wankel engine) more often than maybe once a decade because any change always reduces substantially the technological capacity the firm has accumulated so far and necessitates a new learning process into a different direction. This logic does not only apply to technical choice but to technological choices in the wider sense of the term, particularly with reference to organizational patterns, i.e. intra-firm management practices as well as inter-firm relationships and interaction between firm and supporting institutions.

3.4 Environmental policy and technical change

What does all this imply for the observations presented by Porter and Linde? The answer is that firms are not perfectly rational in their technological behavior, at least not in the sense that orthodox neoclassical economics give to rationality. That is, firms do not constantly change their machinery, production processes, and organizational patterns according to changes in the macroeconomic framework conditions. Rather, their technological behavior is boundedly rational in the sense that it follows a given trajectory or path. Firms do not constantly move from one radical innovation to the next. Following a trajectory or path means, as we have argued above, that there is discrimination against certain technologies (machinery, processes, organizational patterns) that would seem attractive to the external observer. As production is an eternal sequence of optimization problems, it can thus happen that certain factors are constantly neglected. Porter and Linde give the example of U.S. and European firms' problems with quality, something that became obvious only when their performance started to be compared systematically with Japanese firms (e.g. Womack et al. 1990). As the former had optimized towards capacity maximization and intra-firm division of labor, they had become used to tolerating extremely high levels of defect ratios and quality costs.

Pursuing a given trajectory usually means riding down the learning curve. Over time, the effort to achieve improvements increases. There is, however, no obvious point in time for giving up a given trajectory and moving to a new one. This move is often induced by external shocks, for instance the entry of new competitors with radically different, and better, process or product technologies, or government regulation. This is where environmental policy comes in: As it limits emission levels or forces firms to substitute given substances, it modifies the learning trajectory of the firms, i.e. it forces them to move from the current trajectory or path to a new one. Firms are forced to move into uncharted territory. As they have not yet ridden down the learning curve on the new trajectory, they initially face cost disadvantages which will, however, disappear or even turn into gains as they move down the new learning curve. Often, firms will initially try to comply with regulation based on modifications of existing processes. Even this can give rise to efficiency gains as engineers will address a given process from a different angle and may come up with improvements they had not thought of before. Frequently, however, environmental regulation will lead to radical change, like the substitution of solvents which in the end led to an easier process and a cheaper product

3.5 MIPS as a socio-economic device

MIPS is a useful concept in order to get beyond traditional approaches at the micro-level, which have often been slow and costly. As MIPS allows us to measure the resource productivity of processes and products, it can serve as a management rule for economic agents at the micro-level (see Box 3). Within the debate and the research on sustainability, we have found that this is exactly what is missing when searching for possibilities to implement the idea of "[meeting] the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987, p. 43) on the firm level. The firm as a producer of goods and services can therefore implement strategies to save resource and protect the environment individually. Products are environmentally sound when either the amount of material input per amount of services is decreased or the number of services provided by this product is increased. A given firm may come up with different strategies: production can be oriented so that products are long-living, or after-sales services can be offered to increase the life span (and at the same time to increase customers satisfaction) (Haake/Hinterberger, 1998). Similar considerations can be made by consumers.

Box 3: Eco-Audit and Resource-Management

The Wuppertal Instituite conducted a case study on "Eco Audit and Resource Mangement" in cooperation with the Kambium Furniture Workshop, Inc (see Liedtke/Rohn/Kuhndt 1998). The primary issues which the case study was concerned with were the execution of an Eco-Audit according to the rules of the EMAS ordinance (No. 1836/93) as well as life-cycle analysis of solid core wood and particle board/formica kitchens.

As a first step toward obtaining certification under the European Eco-Audit ordinance Kambium put together an ten point environmental policy document which combines environmental protection with its primary business objectives while at the same time featuring the elements required by EMAS-ordinance. In addition, the document contains ambitious demands such as an examination of the environmental effects of the products spanning the entire product line, the regional focus of the firm, as well as their environmentally-friendly energy supply.

All the problem areas and savings potentials identified in the course of the environmental audit were combined to formulate a catalogue of measures from which management - after having made preliminary ecological, economic and legal assessments - selects those areas which are to be included in the environmental program. In order to achieve a steady implementation of the environmental program, every measure was tabulated on a form, on which the responsibilities, deadlines, budgets and any possibly necessary incremental steps toward implementation are enumerated.

(continued)

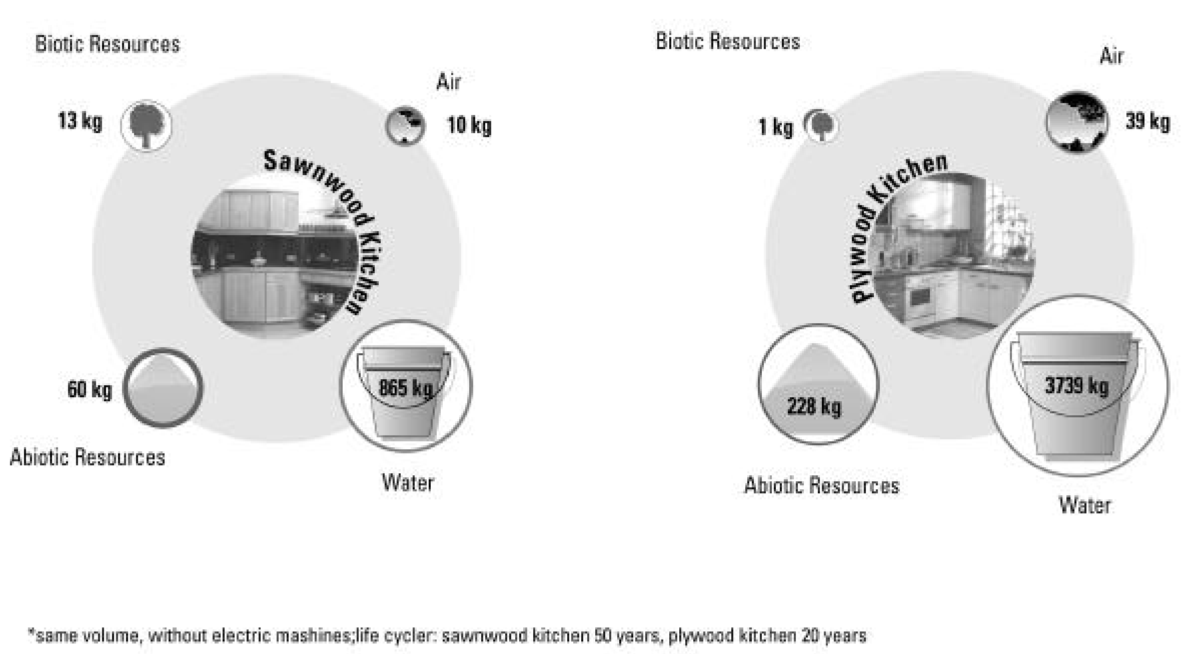
Box 3 (continued)

Yet the approach of Kambium went even further. In light of the comprehensive ecological assessment of Kambium, the environmental effects associated with the product line "solid wood kitchens" were tabulated. These include all material flows attributable to production which were determined and evaluated using the MIPS concept. The material intensity analysis covers the entire life cycle of the kitchen, i.e. from raw material procurement/extraction, through the production of lumber, the assembly of the boards and assorted other parts, to the finished kitchen, the use phase and the recycling or disposal of the kitchen. The material intensity of a solid wood kitchen was computed both for the individual life stages (production, use, recycling/disposal) of the product line "kitchens" as well as for the entire life cycle (Fig. 2). This was compared to an equivalent kitchen constructed of formica-covered particle board.

The storage capacity of an average kitchen according to DIN 18022 was computed to be 2,061 liters/ kitchen (without electric appliances) In the case of the solid wood kitchen, a life span of 50 years was assumed, for the particle board kitchen, a life span of 20 years was imputed

Fig. 2 identifies the solid wood kitchen as a significantly resource saving product. Looking at the life cycle spanning resource consumption, only the input of biotic materials for the solid wood kitchen is (thirteen times) higher than in the case of the particle board kitchen, while t input of abiotic materials, water and air is about four times higher for the particle board kitchen than for the solid wood kitchen. In total, the resource use of the latter is about four times higher.

Fig. 2: Life cycle wide material intensity of a solid wood and a formica/particle board kitchen in kg/l storage space



4 The macro-level perspective: Stimulating organizational and technical change for sustainability

Conventional environmental policy is about reducing environmental damage caused by identifyable substances in identifyable regions with identifyable causalities. In the view of ecological economics and taking a global perspective, this is not sufficient. Rather, it is necessary to reduce the overall material intensity of production and consumtion ("scale") to make the economy ecologically sustainable. Here knowledge is important in at least two respects. The first aspect refers to the limited knowledge that any environmental policy faces, the second to the socio-economic innovation necessary for overcoming this lack.

MI and MIPS can not only be used as a practical device for a company's management and for sustainable consumption. It can also serve as a guiding principle for an ecological economic policy. Ecological taxes or tradable permits can be based on resource flows (see Hinterberger/Luks/Stewen, 1996).

Global environmental problems would be much smaller if the price systems of existing market economies would cover all (or at least the most important) external costs. But the problem is that it is not so easy to even roughly establish a system of relative prices that reflects the "ecological truth" in the sense of an ecological and economic optimum. The strategy of dematerialisation and of a reduction of energy consumption is *not* based on an attempt to establish an allocational optimum; we follow Daly's argument that allocation and scale are competing economic objectives.

Our knowledge that the consumtion of energy and material in general is inducing environmental problems can directly lead us to design environmental policy measures, even if the exact cause of specific problems is unknown or uncertain, which is certainly true in most. Such policy measures can be based on the functioning of markets to reduce the resource intensity of our economies. Whether the system of relative prices then speaks the "truth" is not being measured by whether or not it reaches an abstract economic allocational optimum (which is for many reasons not obtainable). Instead, the decisive criterion is whether it leads *in the long run* to a reduction of the consumption of materials and energy by a factor of ten. As a result the *tendency* of such a policy will be an internalisation of external effects, even if such an internalisation was never an explicit goal. The change in price relation will lead to avoidance of environmentally harmful activities and, therefore, also to a result at which traditional environmental policy aims, but never can reach. We may consider this as a dynamic rather than static single-pareto-optimum based formulation of the concept of internalisation of external effects.

We suggest that the discussion will shift more and more from the consideration of specific toxics and their effects to an analysis of material flows. In this context, lifestyles in western economies will also have to be considered. An ecologically sustainable eco-policy will have to focus on the input side of production processes where human intervention into ecological systems first appear. The goal of such a policy is to reach long-term sustainable development.

To achieve such a development the entire range of environmental policy measures needs to be considered.

4.1 Instruments of Ecological Economic Policy

If we accept the goal of dematerialisation as useful for a strategy for sustainable development, a number of economic instruments can be designed in order to achieve this goal (see Hinterberger/Luks/Stewen, 1996)

Subsidies and Material Flows

In most industrialized countries, a debate over reducing subsidies has been raging for a long time. Only a small portion of the subsidies awarded today serve environmental policy purposes, and where they do, they most often foster "old" environmental policy goals. The state encourages the installation of catalytic converters and filter equipment, but also investment projects involving integrated environmental protection.

However, all subsidies, even if they are not motivated by environmental policy objectives, provide incentives for either ecological or unecological handling of natural resources. A multitude of financial aids and tax breaks have negative ecological repercussions, such as financial support for intensive agriculture, petroleum tax concessions and coal support funds (see deMoor 1997). Alongside these explicit subsidies we also find hidden subsidies worthy of our attention, so-called "shadow subsidies," which result from the fact that certain performances are not paid for in full by those enjoying them. For example, gasoline and automobile taxes do not come close to covering the full costs of automotive traffic (Welfens et al 1995).

Moreover, fixed-term subsidies can play an important role in setting in motion an ecological structural change. The material intensity corresponding to the MAIA-methodology could be used as a general criterion for an ecological reduction of subsidies (Welfens/Gerking 1997).

Taxing Material Inputs

For more than a decade numerous suggestions on an ecological restructuring of the tax code have been raised. That so far no noticeable results have been forthcoming can only be explained by the resistance of societal interest groups–after all, in most eco-tax-proposals no additional taxes are levied; instead, the objective is to restructure the existing un-ecological tax system. One main reason for the system being unecological is that the production factor of labor is taxed above all else. For instance, between 1970 and 1993, the proportion of the total German tax revenue from income and social security taxes rose by 41 % and 37 % respectively, while the tax burden on the consumption of nature fell by 22 %–a trend which also can be observed internationally.

In line with a dematerialization strategy, a further step would be to examine a tax which directly targets material input (MI), using this as the tax base. Energy taxes and MI taxes are birds of similar feather. Both are input taxes – they are not tied to emissions or waste but focussed on the materials entering the economic process. Both tax bases (energy and material input) provide an estimate for the environmental stress potential. Domestically only those businesses would be affected by a material tax which displace primary material directly. If we disregard water and air for the moment, it turns out that only few sectors actually displace material; construction and mining are two prominent examples. For a normal industrial enterprise, the material movement is largely limited to water. All other businesses would only be indirectly affected, by the fact that those businesses which do directly move material would have to raise their prices due to the tax burden. In both cases it is, however, complicated to deal with international trade flows, i.e. to solve the technical problem of calculating the energy content or the "ecological rucksack" of imported material at the border (Stewen 1996).

Certificates on Material Flows

Material input certificates offer a possible alternative to the tax option: (Hinterberger/ Luks/ Deumling 1995, Lemmer 1996). Although certificates theoretically offer various advantages, to date they are hardly used in Europe at all. An MI-certificate would constitute a permission to displace a certain quantity of primary material (following MAIA–in tons of MI). In order to use one of the five types of primary materials in the economic cycle, a given firm would need material input certificates. A national or international authority could determine the permissible extraction quantity as an ecological guardrail, starting from the present level of extraction and reducing this according to the macroeconomic reduction goal (a Factor of 10), and issue certificates in precisely this amount, while setting prices for resource use would be left up to the markets. Whoever wishes to move primary material must then return a corresponding amount of certificates to the issuing authority in exchange. Consumers would only need certificates insofar as they themselves move primary material, for example by drawing water from their own well. But here a level of insignificance should be established, below which no certificates would need to be involved.

Neither taxes on material input nor material input certificates would require universally binding information about the MIPS numbers of all products. The only requirement would be that at the respective site (in the mine, at the point of water removal, perhaps at the location at which air is burned) the appropriate number of certificates are returned or taxes paid. It is realistic to expect that this control problem can be solved as water utilities, mining firms, or plantation owners use to have a fairly clear idea of the amount of materials they are moving. The procedure we suggest would then lead to a situation in which materially intensive products would become more expensive, assuming a corresponding border adjustment mechanism existed in case trading partners did not introduce such measures. In the case of durable products produced with relatively fewer additional material inputs, an incentive exists to use them longer because the price *per use* would end up being lower.

Such an approach has considerable advantages not only in economic terms (as it uses market mechanisms) but also in terms of knowledge. We do not need some central agency which decides upon a rate of reduction of zillions of different materials. Rather, we leave it to the actors in the market to use their knowledge, or to create the necessary knowledge, in deciding which materials they find more valuable than others.

4.2 Innovation for dematerialisation

A dematerialization by a factor of ten can only be achieved if technologies and societal structure and organization look very different tomorrow than they do today. We conceptualize such a transformation as "ecological structural change": the economic structures of a country, of Europe, or of the whole world would thus be transformed in such a way that *as a result* consumption of primary materials would be reduced noticably. Materially intensive sectors wither; others prosper and grow. What will be decisive is whether or not a society–and the world as a whole–succeeds in bringing about the necessary technical and social innovations. The transformation itself is technically possible. Technical change already determines in very important ways the direction in which society moves, and this has been especially true over the *last* 50 years. The goal of global dematerialization by 50 % refers to a period of 50 years–and offers a long-term framework within which step-by-step innovations are to be encouraged in the short term.

A long list of concrete examples shows that such innovations are possible (and that they are economically rewarding as well; Schmidt-Bleek/Tischner 1995, Stahel 1995 und Weizsäcker/Lovins/Lovins 1996). Examples range from FRIA, a combination of pantry and modern cooling technology, built into the kitchen wall, that is durable and meets service demands while saving energy and material, to entirely new guiding principles of a "Sustainable Germany" (Sachs et al 1998). These statements in favour of innovation are not to be misconstrued to mean that innovation is always a good thing or that dematerialization will manifest itself as an extra bonus. On the contrary: most often when innovation cycles are sped up, product durability decreases because products age more quickly due to fashion and technical obsolescence, which, in turn, leads to an increase in resource use. Nevertheless, an innovation dynamic is essential for achieving ecological structural change.

The term innovation not only encompasses technical novelty with regard to products and processes. The aforementioned cold-store "FRIA", for example, requires no technology not already available. What is new is the *idea* of how the service "storing and preserving fresh foods" can be met in a more eco-efficient manner. Entirely new marketing strategies are required when compared to the traditional refrigerator. Suppliers might no longer be multinational corporations, but local installation specialists and construction firms. The structure of the market would change in this particular area, if the system "FRIA" were to be installed over a large geographical area. We may describe such changes using the term (and the theory behind it) "institutional innovation". Simultaneously, the term "innovation" encompasses changes in social structure and organization in the forms of mobility, in other organizational forms of day-to-day activity and so forth.

4.3 Path policy

In our view, the needed structural change need not necessarily and entirely be the outcome of a chaotic and turbulent search process. In formulating an alternative perspective, we again refer to concepts from innovation economics. There is a strong interrelationship between technical change, industrial policy, and environmental policy, at least in the perspective of an unconventional conceptualization which we will call *path policy*. Traditional technology and industrial policy usually does not distinguish systematically between incremental and radical technical change. It usually aims at both, for instance supporting the creation of new technologies and their dissemination (radical technical change), and the continuous technological upgrading (e.g. through SME modernization programs; incremental technical change). Policy formulation and implementation in technology and industrial policy usually did not address the fact that technological development is path dependent but rather conceptualized technical change as a continuous stream of all sorts of innovations. However, if we accept the notion of path dependence, it is quite obvious that technology and industrial policy has played, and can continue to play, a much more important role than is often acknowledged.

Take the example of industrial policy for the electricity sector in 19th century Germany. There were two different, competing concepts how to organize electricity generation and distribution: through a centralized system with large power plants and a wide network, or through a decentalized system with small power plants. Both systems had their technical and economical merits and disadvantages. In the end, the proponents of the centralized system got the upper hand as they were better connected politically. From then on, development of the electricity sector was path dependent for several reasons: due to more development work going on, the centralized system became more mature and efficient; regulatory agencies and training institutions were created to take care of the sector, but they quite naturally had an interest in maintaining its basic configuration; as all this happened, the mindset of policymakers, administrators and engineers changed to the point that the centralized solution appeared as the only reasonable and possible one.

The lesson from this example is: In a situation when development paths (i.e. technological trajectories) are not yet clearly defined, technology and industrial policy can play a crucial role demarcating the development path of a given technological/industrial area for decades to come. After a certain period of time, a decision for one and against another technological development path becomes, by all practical means, irreversible as increased development effort in the "winning" technology, and the creation of all sorts of institutions, let the alternative appear unattractive. In other words, in a situation when there is not yet a development path (because a technology is completely new), or if a given development path is exhausted, technology and industrial policy faces a "window of opportunity" to shape technological and industrial development in a much wider sense than is possible under normal conditions (i.e. when path dependence prevails). In such a situation, technology and industrial policy may shape a development path – thus the term "path policy". Path policy might play an extremely important role in future attempts to reduce the ecological burden of production and consumtion, especially if one accepts the hypothesis that we are currently living in a period where windows of opportunity are already open or likely to open in various fields (like telecommunications and energy due to technical change and a new economic paradigm, or urban transport due to the increasingly obvious disfunctionality of the current system of individual transport).

Path policy must not be confused with planning. In fact, it can be imagined to be the opposite of planning and traditional technology and industrial policy exercises. There often followed a supply-driven pattern: researchers and firms captured government agencies, or the other way round, to develop a given technology which was, after a lot of development, presented to a surprised public. It was by no means a rare occasion that a new technology (think, for instance, of the case of the European HDTV policy; Meyer-Stamer 1994) appeared as an answer to a question that nobody had asked, and that actually few found interesting. Under a supply-driven approach, the latitude for creative dealing with new technology, for decentralized shaping, had necessarily to be limited: In order to convince the public of the advantages of a new technology, it had to be already quite highly developed – only without "SNAFUs" would the technology appear convincing.

In practical terms, two variants of path policy can be imagined. Number one would be a variant that has been suggested by Soete et al. (1993). They argue that it can make a lot of sense that the state makes sure that decision on a new development path is not taken prematurely, for instance by financially supporting parallel technological developments for a certain period of time. The pitfall of this variant is that it can become extremely costly, particularly in the case of large technical systems.

Variant number two are broadly based, moderated search processes that involve various actors. Instruments like consensus conferences (Sclove 1994, TAB 1996) or "future workshops" (*Zukunftswerkstätten*, Jungk and Müllert 1989) may be helpful in this context (Meyer-Stamer 1997). Approaches like the local Agenda 21 process may also be helpful in this context. The suggestion to use such instruments may appear like daydreaming. However, in a normative view it is a preferable alternative to laissez-faire, i.e. giving up the attempt to govern the fate of a society and economy, and to centralized, etatist governance which would not work anyway. Moreover, a lot can be learned for this variant of technology and industrial policy from the creation and evolution of the Internet (Meyer-Stamer 1996) which is an open, decentralized system that gives a lot of opportunities not only to firms like service providers, content providers, and software vendors, but also to users. It is structured in such a way that it stimulates rather than curtails creativity and learning.

This is not to say that a participatory approach to path policy is a panacea. Path policy will largely be based on policy networks, i.e. a not formally established but often well-functioning structure that involves a series of actors which in given policy arena have both resources to offer (which will often be concepts and information rather than money) and an interest in the specific shape of the sectoral policy concerned. It is undisputable that policy networks can fail for a number of reasons; Messner (1997, 190 ff) has outlined seven idealtypical constellations of network failure. However, unlike traditional top-down industrial policy where failure, or at least an enourmous waste of money, is almost the rule, policy networks seem to work surprisingly often.

The key problem, it seems, is that we need radical innovation in both the field of technological hardware (i.e. much more resource-efficient processes and products) and organizational patterns (i.e. the way societies govern themselves). We cannot know in advance what these innovations may look like. We should rather try to create conditions for open search processes, based on competition, to generate knowledge on which approaches work and which do not.

5 Knowledge and Environment: a tentative Synthesis

We argue that knowledge plays a crucial role in reducing the materials intensity of the economy. This involves theoretical aspects of understanding technical change and industrial development, and political aspects of implementation.

5.1 The Theoretical Challenge

There are two ways of addressing the interrelationship between knowledge and dematerialisation. First, there is the quite obvious proposal of substituting knowledge for materials. An example would be demand-side management in the energy sector, i.e. using knowledge of energy advisors / consultants to make better user of energy rather than building new power stations.

Second, there is the challenge of creating the conditions to make informed decisions about materials intensity in economic transactions. Instruments like the MIPS concept may prove extremely helpful in creating the knowledge-base to do this. MIPS is a concept that largely rests on the market mechanism as the most efficient means of deciding between technical and organizational alternatives, yet within a given framework ("ecological guardrails").

The strategy of dematerialisation trusts essentially in changes of behaviour due to changes in our socio-economic frame of reference, but also in a change of direction of technical progress as a result of the implementation of environmental policy and "path policy". Additionally, individual preferences for economic as well as ecological circumstances will consciously and unconsciously change as a result of earlier decisions made by governments and economic agents themselves. An evolutionary description of ecological and economic processes seems therefore to be appropriate if we want to describe the interaction of natural and social systems (Hinterberger 1994a, 1994b). A main advantage of evolutionary economics is its capacity to view technologies and preferences as endogenous (Dosi 1988). Here, the relationship of resource productivity and growth dynamics in market economies is of special importance to our considerations. Economic growth is the result of a complex endogenous economic self-organisation process. An evolutionary approach adds this to the neo-classical explanation, which maps growth as exogenously based on individual preferences and technical progress which are not determined by economic processes (Mokyr 1990).

In this way the impacts of human activities on the ecological condition of an economic system appear in a different light. Although every socio-economic development is the result of human action but not of human design (Hayek 1967), what needs to be discussed here is the possibility to influence by economic and political means the economic development so that it proceeds in a desired direction. In other words, what is being considered is the political economy of an environmentally sound structural change. Any measure of environmental policy needs to be designed in a way that it does not impair a market economy's tendency to create innovations and, at the same time, keep the economic development within "ecological guard-rails". Instead of searching for instruments that try to establish a certain future economic structure, such a policy needs to induce an innovative process which opens new ecological market opportunities and reduces others (those which are less ecologically sound). In such a process creativity and new knowledge, that is, technical progress in the Schumpeterian sense, needs to be explicitly considered in an analysis of such processes. An ecological development of a market economy means to develop products and services for the future which take the limited buffering capacity of eco-systems into account but, at the same time, provide a sustainable satisfaction of human needs.

If such a development is within the potential range of possibilities of a market system's capacity to create innovations, the direction of the socio-economic development is not only influenced by financial incentives, but also by the institutional or value system of a society and its organisational structure. These factors are–more than economic factors–regionally diverse and are only partially implemented by formal regulation. In order to achieve an ecological change of our economic development it will be necessary to consider also these factors influencing individual behaviour of households and firms.

5.2 Ecological Economic Policy in a Complex World

Uncertainty is a fundamental characteristic of the complex world which surrounds us. This uncertainty must not–as Hans Jonas has put it– "discourage us from acting," but should rather "encourage us toward action." Knowing how to deal with uncertainty, having the "courage of responsibility" is crucial for our future. Acting only after it is too late might guarantee the people of the industrialized world a few more years of unexamined familiarity, but in the long run we can hardly expect to enjoy the quality of life we have come to appreciate. The concept of dematerialisaion can serve, if it is further developed and democratically legitimated, as the guiding principle in order to reduce the consumption of the environment in such a way that both the ecological and socio-economic conditions for sustainable development are met. This would provide opportunities for an innovative, open, democratic and socially beneficent economic policy and way of life.

Increasing the resource productivity alone is not sufficient, though, if economic growth eventually eats up these improvements. We also need to re-envision what we think quality of life actually means. To achieve both an increase in resource productivity and an increase in the quality of life, technical and social innovations will be required on a large scale. This can succeed if an ecological economic policy arranges the ecological guardrails in such a way that they meet the requirements of the concept of dematerialization. These *guardrails* will only achieve the desired result if the corresponding *guiding principle* is both acceptable to and rooted within society. Dematerialization means achieving a sufficient reduction in global material flows by markedly increasing the resource productivity throughout all economic sectors, to maintain the quality of life in the wealthier parts of the world while substantially increasing it in the countries of the South.

Bringing together ideas and approaches from economic theories, usually thought to be mutually exclusive, and being mindful of other social-scientific insights, appears to us necessary in order to reach practical and problem-specific recommendations for decision-making. This is the only way to afford the necessary reduction in external environmental effects while at the same time supporting market competition as a "discovery procedure" for ecologically and economically promising innovations.

A command and control based environmental policy as we know it today cannot contribute very much toward sustainable development. The function of dematerialization as a guiding principle and guardrail, as we have advocated it here, seems to us to be a democratic basis for an ecological economic policy. In the long run such a policy provides more freedom of choice than an environmental policy which attempts to "solve" an increasing number of new environmental problems by issuing new regulations. In our understanding of economic processes, governmental interference has its place in a complex society, but not in the sense of mechanically steering certain economic variables. The realization that one cannot plan structural change does not lead us to a laissez-faire position in environmental policy. Ecological problems are not going to solve themselves. But if, on the other hand, ecological structural change is not conceivable without markets, we have a need for appropriate changes in both the framework and in institutions. The long-range orientation of this policy is a contributing factor here–an orientation suitable for increasing the credibility of the legal framework, while stabilizing the expectations of economic actors. Politics can address these issues better if it accepts that neither the results nor the processes themselves can be precisely guided or even predicted.

Bibliography

Adriaanse, Albert et al. (1997). *Resource Flows: The material Intensity of Industrialized Economies*. Publication by the World Resources Institute, Wuppertal Institute, Netherlands Ministery of Housing, Spatial Planning and Environment, National Institute for Environmental Studies.

Daly, Herman E. (1991). *Steady State Economics*. 2nd ed. Washington, D.C.: Island Press

Dosi, Giovanni. (1982). Technological Paradigms and Technological Trajectories: A Suggested Interpretation of the Determinants and Directions of Technical Change. *Research Policy, Vol. 11*, No.3, pp.147-62.

Dosi, Giovanni. (1988). Sources, Procedures, and Microeconomic Effects of Innovation. *Journal of Economic Literature*, *Vol. 26*, pp.1120-71.

Freeman, Christopher. (1987). *Technology Policy and Economic Performance. Lessons from Japan.* London, New York: Pinter.

Freeman, Christopher. (1991). The Nature of Innovation and the Evolution of the Productive System. In *Technology and Productivity. The Challenge for Economic Policy* (pp.303-314). Paris: OECD, The Technology Economy Programme.

Haake, Julia, and Hinterberger, Friedrich. (1998*). Product Durability. Economic and Ecological Aspects.* In Dwyer, S., Ganslosser, U. and O'Connor, M. (Eds.). Ecology. Society. Economy: Life Science Dimensions. Filander Press.

Hayek, Friedrich A. von. (1967). The Results of Human Action but not of Human Design. In: idem, Studies in Philosophy, Politics and Economics. Chicago.

Hinterberger, Friedrich. (1994a), *Biological, Cultural, and Economic Evolution and the Economy/Ecology Relationship*. In: Straaten, Jan van der / Bergh, Jeroen van den (Eds.) (1994), Toward Sustainable Development - Concepts, Methods and Policy. Washington, DC: Island Press.

Hinterberger, Friedrich. (1994b): *(Ko-)Evolution von Natur, Kultur und Wirtschaft. Einige modelltheoretische Überlegungen*. In: Beckenbach, Frank and Diefenbacher, Hans (Ed.), Zwischen Entropie und Selbstorganisation, Marburg: Metropolis.

Hinterberger, Friedrich, and Wegner, Gerhard. (1997). *Limited Knowledge and the Precautionary Principle: On the Feasibility of Environmental Policies*. In Jan van der Straaten and Jeroen van den Bergh (Eds): Economy and Ecosystems in Change. Analytical and Historical Approaches. Cheltenham: Edward Elgar.

Hinterberger, Friedrich, Luks, Fred, and Deumling, Reuben. (1995). *The Economics of Limited Material Throughput.* Paper presented at the Annual Meeting of the Austrian Economic Association.

Hinterberger, Friedrich, Luks, Fred, and Schmidt-Bleek, Friedrich. (1997). Material Flows vs. 'Natural Capital'. What Makes an Economy Sustainable? *Ecological Economics Vol. 23,* No. 1, pp. 1-14.

Hinterberger, Friedrich, Luks, Fred, and Stewen, Marcus. (1996). *Ökologische Wirtschaftspolitik. Zwischen Ökodiktatur und Umweltkatastrophe*. Birkhäuser, Berlin. Forthcoming in English: London: Routledge.

Hinterberger, Friedrich, Moll, Stephan, and Femia, Aldo. (1998). *Arbeitsproduktivität, Ressourcenproduktivität und Arbeitsintensität des Ressourcenverbrauchs.* Mimeo.

Jungk, Robert, and Müllert, Norbert R. (1989). *Zukunftswerkstätten. Mit Phantasie gegen Routine und Resignation.* München: Heyne.

Kemp, René, and Soete, Luc. (1992). The Greening of Technological Progress. An evolutionary perspective. *Futures,* June, pp.437-57.

Lemmer, Andreas. (1996). *Material-Input-Zertifikate als Instrument zur Reduktion von Stoffströmen.* Wuppertal Paper.

Liedtke, Christa, Rohn, Holger, and Kuhndt, Michael. (1998). Eco-Audit and Resource Management of Kambium Möbelwerkstätte GmbH. *Journal of Industrial Ecology.* Forthcoming.

Luks, Fred. (1998). *Der 'steady state' als Grundlage eines sustainable development.* PhD dissertation.

Merten, Thomas et al. (1995). *Materialintensitätsanalysen von Grund-, Werk-, und Baustoffen (1). Die Werkstoffe Beton und Stahl. Materialintensitätsanalysen von Freileitungsmasten.* Wuppertal papers No. 27.

Messner, Dirk. (1997). *The Network Society. Economic Development and International Competitiveness as Problems of Social Governance.* London, Portland: Frank Cass.

Meyer-Stamer, Jörg. (1995). The High-Deficit Television (HDTV). Die Politik des hochauflösenden Fernsehens in Europa. In Lutz Erbring (Ed.), *Kommunikationsraum Europa* (pp. 74-84). Konstanz: UVK Medien/Ölschläger.

Meyer-Stamer, Jörg. (1996). Das Internet als Beispiel dezentraler Techniksteuerung - Konsequenzen für Technologiepolitik in Deutschland. In Hans J. Kleinsteuber (Ed.), *Der "Information Superhighway". Amerikanische Visionen und Erfahrungen* (pp. 139-47). Opladen: Westdeutscher Verlag.

Meyer-Stamer, Jörg. (1997). Neue weltwirtschaftliche Herausforderungen und Optionen einer zukunftsfähigen Unternehmens-, Technologie- und Wirtschaftspolitik. In Jörg Friedrich Mayer (Ed.), *Agenda 21 für Niedersachsen - Stand und Perspektiven einer nachhaltigen Entwicklung auf regionaler Ebene* (pp. 18-29). Loccum: Evangelische Akademie (Loccumer Protokolle, 24/97).

Mokyr, Joel (1990). *The Lever of Riches: Technological Creativity and Economic Progress.* New York, Oxford: Oxford University Press.

Nelson, Richard R. (1992). National Innovation Systems: A Retrospective on a Study. *Industrial and Corporate Change, Vol. 1*, No.2, pp.347-74.

OECD. (1992). *Technology and the Economy. The Key Relationships.* Paris: OECD, The Technology/Economy Programme.

Porter, Michael E., and Linde, Claes van der. (1995). Green and Competitive: Ending the Stalemate. *Harvard Business Review, Vol. 73*, No. 5, pp. 120-34.

Sachs, Wolfgang, and Loske, Reinhard. (1998). *Greening the North*. Zed Books.

Schmidt-Bleek Friedrich (1994). *Wieviel Umwelt braucht der Mensch? - mips - Das Maß für ökologisches Wirtschaften*. Birkhäuser Verlag, Berlin, Basel, Boston: Birkhäuser.

Schmidt-Bleek, F. (Hrsg.) (1996): MAIA - Handbuch für Materialintensitäts-Analysen. Wuppertal: Wuppertal Institut.

Schmidt-Bleek, Friedrich, and Liedtke, Christa (1995). *Key Words in Environmental Policy*. Wuppertal Papers Nr. 30, Wuppertal.

Schmidt-Bleek, Friedrich, and Tischner, Ursula. (1995). *Produktentwicklung, Nutzen gestalten - Natur schonen.* Schriftenreihe des Wirtschaftsförderungsinstituts Österreichs, Nr. 270. Wien.

Schmidt-Bleek, Friedrich et al. (1998). *MAIA - Einführung in die Materialintensitätsanalyse*. Wuppertal Texte. Berlin, Basel, Boston: Birkhäuser.

Schumpeter, Joseph A. (1964). *Geschichte der ökonomischen Analyse.* Vandenhoeck and Ruprecht, Göttingen.

Sclove, Richard E. (1994). *Citizen-based technology assessment?*. The Loka Institute, Amherst (mimeo).

Soete, L., et al. (1993). *An Integrated Approach to European Innovation and Technology Diffusion Policy.* Brussels-Luxembourg: ECSC-EEC-EAEC (Publication No. EUR 15090 EN of the Commission of the European Communities).

Stahel, Walter R. (1995) *Handbuch Abfall*. Herausgegeben von der Landesanstalt für Umweltschutz Baden-Württemberg. Bd. 1 und 2, Karlsruhe.

TAB. (1996). Konsensus Konferenzen - Ein neues Element demokratischer Technologiepolitik? *TAB Brief*, No. 10, pp. 4-10.

WCED (World Commission on Environment and Development). (1987). Our Common Future, Oxford/New York: Oxford University Press.

Weizsäcker, Ernst U. von, Lovins, Amory B., and Lovins, Hunter (1996). *Factor Four. Doubling Wealth - Halving Resource Use*, Zed Books.

Welfens, Maria J., and Gerking Doris. (1997). *Ökologisch Zukunftsfähige Subventionspolitik.* Wirtschaftsdienst, No.3/1997, pp. 159-165.

Womack, J. P, Jones, D. T., and Roos, D. (1990). *The Machine that Changed the World.* New York: Rawson.