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Abstract

The aim of this paper is to contribute to an innovative agenda in the field of Environmental Economics. The paper focusses on a conceptual and political perspective on the interactions between nature and economy. Section 1 states that Environmental Economics has to consider three fields: nature, justice and the role of time. To operationalize this claim, we introduce fundamental concepts such *as entropy, joint production, ignorance, evolution, absolute scarcity, responsibility* and *homo politicus* and explain them in Section 2. These concepts are applied in Section 3 using a historical example, namely the soda-chlorine industry, extending over a period of about three centuries. The lessons taken from this economic, environmental and political *evolution* are outlined in Section 4. In Section 5, we apply the concept of *responsibility* to address political aspects dealt with when examining the interplay between nature and economy. In our outlook in Section 6, we argue that these concepts and further concepts do not form a hierarchically structured system. Instead they are conceived as a network of interdependent concepts that reference each other but also remain categorically distinct from one another.

JEL Classification B4, B5, D72, Q50, Q 53, Q55, Q57

Key words: *absolute and relative scarcity, evolution, joint production, ignorance, responsibility, power of judgment, homo politicus*

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1. Introduction: Central aspects of environmental problems: nature, justice and time

Rethinking the field of environmental economics in a visionary and perhaps provocative way demands that the research agenda deals with three fields: nature, justice and time. These dimensions are so encompassing that it is necessary to show how they can be approached in an operational way. This paper attempts to contribute to this task. We shall do this by developing an approach which is based on fundamental concepts such as *absolute scarcity*, *evolution*, *ignorance*, *joint production* based on thermodynamics, responsibility, *power of judgment* and a new understanding of human behavior, the *homo politicus*. This demands *knowledge* from different fields. We note that "in modern times, the sciences give us access to all of these fields. No single individual can master all of those sciences at once. Even if there were such a universal genius with outstanding expertise in economics, law, the social sciences and the natural sciences, especially physics, biology and chemistry, that individual still would not possess the skills to bring all of that knowledge together into a comprehensive understanding or help achieve such a comprehensive understanding and its network of concepts" (Faber et al. 2018: 6).

The concepts we propose provide an interdisciplinary approach to environmental problems and make it possible to identify and systematically organize the knowledge necessary to solve these problems. In doing so, the complexity of environmental-economic interaction can be reduced. The challenge is thereby transformed into concrete questions and made accessible in practical terms for environmental policy measures. We will argue on theoretical, historical, economic, natural scientific, ethical and political levels.

After explaining the six concepts mentioned above in Section 2, we will illustrate them with a historical example, the development of the soda-chlorine industry ranging over a period of 300 years, from 1750-2050 (Section 3). In Section 4 we show the lessons that can be drawn from the *temporal* structure of the economic environmental interactions, *ignorance*, scope of the problems, the actors behind them, and their solutions.

In Section 5, we apply the concept of *responsibility* to address problems occurring in the interplay between nature and economy. Since the ability of individuals to assume *individual responsibility* is narrowly limited by their *ignorance*, another dimension of *responsibility* needs to be employed: *political responsibility*. The latter takes into account a central challenge for effective environmental policy, the occurrence of *ignorance* and even *irreducible ignorance*. In order to deal with it, the faculty of *power of judgment* is introduced and assigned to the *homo politicus*. The latter does not substitute but complement the *homo oeconomicus* model. In our outlook in Section 6, we argue that these concepts do not form a hierarchically structured system. Instead they are conceived as a network of interdependent concepts that reference each other but also remain categorically distinct from one another (Faber et al. 2018). From this follows that it is important to find

further concepts to reduce the complexity of environmental issues and structure existing *knowledge*, thus enabling policymakers to be guided by responsibility when taking practical action.

2. The concepts

In our past research we have worked with about 15 general concepts that are fundamental to understanding the world (see Faber et al. 2018). They are constitutive concepts of nature, such as *entropy*, and concepts from the social sciences like *homo politicus*. In this section we want to limit ourselves to six of them and explain their fruitfulness by using them to examine the interaction of nature and economy by illustration of the soda-chlorine industry.

First, we turn to the notion of *absolute* and *relative scarcity*. Thereafter, we explain a central concept in the field of time, that of *evolution*. In almost all our previous studies on the impact of the economy on the environment, *time* has played a prominent role (e.g. cf., Faber, Proops in cooperation with Manstetten 1998; Faber Proops Speck in cooperation with Jöst 1999; Klauer et al., 2017). In doing so, we have repeatedly found that not only are *knowledge* and *novelty* relevant for our research, but above all the explicit consideration of *ignorance* as well.

Two of the six concepts are of particular importance in this paper; the concepts of production, especially *joint production*, and *responsibility* since they "attempt to capture the physical and the moral side of economic production. Both terms exhibit a structural relatedness, which is why they are especially well suited to more precisely define the requirements of practical politics in their relationship to the environment. Finding such concepts or principles is always a matter of *judgment* (Klauer et al. 2017: Chapter 7) because these concepts cannot be deduced from a series of potentially different types of observations. The *power of judgment*, our fifth concept, has the ability to reflect on such possible principles that may allow us to understand differing fields and how they are interrelated" (Faber et al. 2018: 6). Finally, we come to our human actors, the *homo oeconomicus* and *homo politicus.*

Absolute and Relative Scarcity

The concept of *absolute scarcity* of nature was introduced into classical economic thought by Thomas Robert Malthus. Examples of *absolute scarcity* are water in a desert or water and food in a besieged castle. Similarly we experience today that certain environmental goods are becoming scarcer and scarcer, as is the case in the loss of biodiversity (Baumgärtner et al. 2006a).

Economics prominently employs another type of *scarcity*: the concept of *relative scarcity*, i.e. a good is scarce in relation to other scarce goods. Scarce goods have a positive price.

The price of non-scarce goods is zero. The use of *relative scarcity* implies that each good can be substituted. As the example of the loss of biodiversity shows, this is not always the case. The same holds for the consequences of climate change, such as water *scarcity* or regular flooding. Here we are talking of *absolute scarcity*. The longer the time period, the more urgent is the phenomenon of *absolute scarcity*.

Evolution

While the concept of space is relatively easy to grasp, the concept of time is much more difficult to perceive. The nature of time has been - already in Greek philosophy - a source of contention (Klauer et al. 2017: Chapter 8). To understand and analyze the interplay between nature and the economy, we need a broad view of time since we have to consider short, medium and in particular long-term repercussions. Hence, we have to structure the flow of time. What then is an appropriate concept of time? A good starting point to get an idea of temporal structures is the concept of evolution. Evolutionary economists (e.g. Nelson and Winter 1982) started their research in the 1960s by following Joseph A. Schumpeter's ideas of evolutionary thought, developed in his seminal work *The Theory of Economic Development* (1934; first published in German in 1912). However, this work had little impact on the research of environmental economists. With the development of ecological economics in the 1980s, evolution became a key concept (e.g. Norgaard 1984; Faber and Proops in cooperation with Manstetten 1998; Schiller 2002).

The concept of evolution is fruitful for the interaction between nature and the economy because it allows us to combine the structure of *time* with concepts such as *ignorance* and *novelty*. "For instance, the concepts of genotype (the gene structure of a living being) and phenotype (the realization of a living being) can be employed not just in a biological context but also in a physical and economical context. This broad view of evolution is useful for two reasons: (i) Several concepts first introduced in natural science are useful because they provide economics with a physical foundation. (ii) The way natural science has treated time and irreversibility offers important lessons to economics, for many economic actions have irreversible consequences, like the use of groundwater which cannot be replaced if it is extracted too fast." (Faber et al. 2018: 12) To give an example, the *invention* of a technique can be interpreted as a genotypic change of an economy, while the actual realization, the *innovation*, can be seen as a phenotypic development. As we will see in the following Section 3, the time lag between *invention* and *innovation* can be rather long.

Individuals, scientists and politicians who are concerned about the environment are particularly interested in long-term developments during which *novelty*, in our terminology genotypic change, can unfold; here *time*, *evolution* and *ignorance* are of particular relevance. However, "many branches of science tend to conceive of their objects of study as rather timeless; they tend to represent their findings in 'eternal' laws, such as the Law

of Classical Mechanics. The application of such kinds of science easily leads to the belief that future events are predictable. This predictability would have been complete for that ideal scientist, Laplace's demon (Prigogine and Stengers 1984). In contrast to this approach, we start from the assumption that the objects and their relationships which science examines are intrinsically characterized by complete or partial emergence of *novelty* in the course of time. This leads us to develop new concepts to answer this question. A key notion for our approach is *evolution*". (Faber et al. 2002: 136).

We employ a general concept of *evolution* (developed at length in Faber, Proops in cooperation with Manstetten 1998: Part II and III) to be able to understand and deal with long-term interactions between economic activity and its impact on the environment, and vice versa. By employing concepts from biology and physics in addition to economics, we can identify the extent to which we can and cannot predict long-term developments. This enables us to become aware of our *ignorance* and to incorporate this *knowledge* explicitly into our theorizing and policies, which is particularly relevant for environmental policy making.

Knowledge, Novelty and Ignorance

Focusing our attention on our *ignorance* instead of our *knowledge* creates a decisive shift in economic theory and environmental policy. When dealing with an environmental problem, we often notice that we do not know whether we are able to solve it or not. One reason for this state of affairs is that we are not aware of what we can know and what we cannot know. To clarify this important question, an analysis of *ignorance* is needed. We have dealt with this epistemological question in Faber, Manstetten, Proops (1992a; 1992b)[2], where we develop a classification with eight forms of *ignorance*. A deepened understanding of *ignorance* yields new attitudes towards environmental problems: attitudes of openness and flexibility instead of control and inflexibility.

Knight (1921) differentiated between 'risk' and 'uncertainty'. Risk occurs when not only all possible outcomes are known, but also their probabilities. In the case of uncertainty, only the outcomes but not their probabilities are known. *Ignorance* occurs if we do not know the outcomes in advance. To give an example: Most people were ignorant concerning the catastrophe in Fukushima in Japan in 2011.

In contrast to *risk* and *uncertainty*, *ignorance* has not yet received the attention it deserves in economics. Or, as Hayek (1972: 33, our translation) put it: "Perhaps it is only natural that the circumstances which limit our factual *knowledge* and the ensuing limits to applying

[2] See as well: Faber, Manstetten, Proops, 1998: chapter 11; Faber, Proops in cooperation with Reiner Manstetten 1998: chapter 7; Faber, Manstetten 2010: Chapter 4, see also Funtovicz & Ravetz 1991; Smithon 1988. In contrast to these authors, we shall place special emphasis on aspects of time and *evolution*, for our special interest has been evolutionary problems in a broad sense, including environmental questions as particular cases.

our theoretical *knowledge* go rather unnoticed in the exuberance which has been brought about by the successful progress of science. However, it is high time that we took our *ignorance* [our emphasis] more seriously."

In the following Sections 3 and 4 we shall employ several forms of *ignorance* from our classification referred to above. Important for our argumentation below are the following:

- *Individual* and *social ignorance*: *Ignorance* can be ascribed to the individual, a community or even a society. In the first case, we speak of *personal* or *individual ignorance* because the required information is generally available within a society but unknown to the individual. The second falls into the category of *social ignorance*, i.e. the required information is unavailable not only on an individual level but also to the society. These types of *ignorance* can be reduced by learning on a personal level and by science on a communal level (Faber et al. 1998: 116).
- *Closed* and *open ignorance*. We speak of *closed ignorance* whenever we are unaware of our *ignorance*. The possibility of risk, uncertainty and surprise remains unexpected in this case. In contrast *to closed ignorance*, *open ignorance* occurs when individuals, communities or societies are aware of it and are in a state of openness towards their *ignorance* (ibid.: 116f).
- *Reducible* and *irreducible ignorance: Reducible ignorance* can be overcome by learning and by science. In contrast to that, *irreducible ignorance* cannot be reduced by the accumulation of *knowledge* (ibid.: 118f)

In the following, we link the concept of *ignorance* with the concepts of *joint production* and *responsibility*. The consequences of *joint products* for the environment need to be taken into account, as do the *responsibility* of economic and social actors for dealing with those consequences. To be responsible, however, requires the ability to foresee the consequences of one's actions, as we will explain in Section 4. Thus, *responsibility* raises the problem of the limits of *knowledge* and, in turn, of *ignorance*.

Joint Production

The notion of *joint production* describes the phenomenon that several outputs *necessarily* emerge from economic activity[3]. It can "capture the essential thermodynamic constraints of production processes, as expressed by the First and Second Laws of thermodynamics, through an easy-to-use and easy-to-understand economic concept. This holds for production in both economic systems and ecosystems. *Joint production*, therefore, is also a fundamental notion in ecology even though it is not often expressed as such in that discipline. Organisms and ecosystems as open, self-organizing systems, necessarily take in several inputs and generate several outputs, just as an economy does. Indeed, such natural systems are the earliest examples of *joint production*." (Baumgärtner et al. 2006: 5). In

[3] Georg Müller-Fürstenberger (1995) conducted a pioneering theoretical and empirical study on joint production in the chemical industry.

summary, *joint products* are an essential element to formulate the biophysical constraints of economic activity. They relate to the repercussions of production and consumption on the environment.

The occurrence of joint production has been well known since the beginnings of agricultural activity; an example is sheep farming: A sheep does not only yield milk, but also wool and finally meat. All sectors of modern economies are characterized by *joint production*. This is particularly true in the chemical industry where many of the *joint products* are useful. But in the meantime, everyone knows that *joint production*, as for example the production of steel, yields unwanted goods, so called bads, such as dust, waste water, slug, CO_2, which are unwanted because they damage the environment.

"The power and generality of *joint production* can be demonstrated through the way it embraces four central issues in ecological economics: irreversibility, limits to substitution, the ubiquity of waste, and the limits of growth" (ibid.: 5)[4].

There exists a close relationship between *joint production*, *responsibility* and *ignorance* as will be shown in Section 3 below.

Responsibility

Responsibility is a ubiquitous phenomenon. The concept of *responsibility* broadens the scope of our economic investigation to incorporate an ethical perspective which is based on philosophical reasoning. This is particularly important since "economic activity generally produces two kinds of output: the intended principal product and unintended by-products. We would expect, and indeed observe, that producers will focus their attention and energies on the former, while the latter will be largely ignored, at least to the extent permitted by legal constraints and social mores. This inattention to the undesired products raises two issues of a philosophical nature, one relating to *responsibility*, that is ethical, and one relating to *knowledge* that is epistemological." (ibid.: 7-8).

What is *responsibility*? It links the consequences of an action to the actor. There are several forms of *responsibility* (see ibid.: Part III). In everyday life, the distinction between moral and legal *responsibility* is well known. Less familiar is the distinction between individual and collective *responsibility*. One form of the latter is *political responsibility*.

"Ascribing *responsibility* in this differentiated way helps to reduce complexity, for it shows who is responsible for what and to what extent. This allows us to distinguish between reality and wishful thinking" (Faber et al. 2018: 15).

Responsibility is also an important notion for the understanding of the concepts of *homo oeconomicus* and *homo politicus*, for these two pictures of humankind are characterized by different ranges of *responsibility*: Homo oeconomicus is responsible for his own concerns

[4] For more details see Baumgärtner et al. (2006: 5f.) and Baumgärtner (2000).

and his compliance with legal limits. *Homo politicus*, in contrast assumes *responsibility* for the good state of the community and its sustainable orientation (Faber, Manstetten, Petersen 1997).

Power of Judgment

Power of judgment is a certain capability which cannot be taught, but can only be learned by experience. "In contrast to the discursive reasoning of mind, the judgments of the *power of judgment* are not necessarily logically consistent, each time repeatable and necessary (Kant 1960.II: 184). The judgments of *the power of judgment* do not fulfill the latter three conditions since they have an irrevocable element of freedom and spontaneity and refer strongly to practical *knowledge* based on everyday experiences" (Petersen et al. 2000: 141-142; our translation).

The concept of *power of judgment* has a long history in philosophy. As early as antiquity it was analyzed at length by Aristotle during the 4th century B.C. Its revival came with the seminal work of Immanuel Kant in the 18th century. As Kant put it, "We need judgment when we wish to make practical use of or follow a theory. […] Thus judgment must 'subsume' specific or practical circumstances under rules and concepts. This is necessary when action needs to occur" (Klauer et al. 2017: 99). We illustrate this statement with the famous quote by Martin Luther: "Here I stand, I cannot do otherwise. God help me, Amen!" (Faber, Manstetten 2010: 65; see also 64-67).

Power of judgment was a prominent concept in economics during the 18th and 19th centuries. However, it fell into oblivion in economics when mathematics started to be increasingly employed over the course of the 20th century. It had its renaissance in Ecological Economics at the end of the last century, for environmental politics needs this concept to a considerable extent (Klauer et al. 2017: chapter 8-10; Petersen, Faber, Schiller 2000), as we will show in Section 5.

Homo Oeconomicus and Homo Politicus

The concept of the *homo oeconomicus* is perhaps the most central assumption of economics because it is still a central pillar of economic theory. However, it is claimed by Behavioural Economics as well as various heterodox economic approaches that this concept of human behavior in economics is not as relevant empirically as assumed in major economics textbooks. As argued by ecological economists, the major reliance on the homo oeconomicus is a hindrance in achieving a sustainable policy, for it undermines individual beliefs in a good society and because the homo oeconomicus is solely self-centered (Petersen and Faber 2001).

Nevertheless, this concept captures one important trait of human beings, their self-orientation. For this reason, the concept enables scientists to gain valuable insights into

economic behavior and even to a certain extent into political behavior, which form the basis for economic policies (Downs 1957).

Behavioral economics and heterodox approaches hold that the concept of *the homo oeconomicus* has not to be substituted but supplemented with other conceptions of humans. In this paper, we propose as an additional dimension of human behavior the concept of *homo politicus*. The roots of *homo politicus* originate from Political Philosophy, in particular from Aristotle, Kant and Hegel (see e.g. Faber, Manstetten, Petersen 1997 and Faber, Petersen, Schiller 2002; Hottinger 1998; Manstetten, Hottinger, Faber 1998).

The *homo politicus* is interested in justice, the common good, and in sustainability of natural living conditions. A major difference between the *homo oeconomicus* and *the homo politicus* is that the former is limited to a short-term time perspective, while the latter has a long-term one too. That perspective enables her/him to care also for long-term interests, in particular for securing the sustainability of the natural living conditions. Facing the complexity of *novelty* and *ignorance* linked to a long-term perspective, the *homo politicus* requires a particular faculty in order to make good decisions, the faculty of *power of judgment.*

We note in passing that the empirical relevance of the concept of *homo politicus* was shown in Petersen and Faber (2000).

3. The case study of the Soda-Chlorine Industry

In this section, we apply the concepts introduced – *absolute and relative scarcity; evolution; ignorance; joint production; responsibility; power of judgment* and homo *oeconomicus and homo politicus* – to an example from history and examine the theoretical and practical insights that can be obtained from them.

Applying the different scientific concepts dealt with in Section 2 above can be challenging, especially since they originate from very different disciplines. In order to facilitate an understanding, we will illustrate them with a case from industrial history. The history of the soda-chlorine industry exemplarily shows the close connection between the development of an industrial structure, *scarcity* of natural resources, environmental pollution and the reactions of economic agents and politics (see Müller-Fürstenberger 1995:179-221; Baumgärtner et al. 2006: 292-306). The soda-chlorine industry has been of great economic significance because in the 20th century this industry made up about 60%, of Germany's chemical industry and was thus an important driver of economic growth.

We use its history to show the effects of the use of natural resources, of inventions and innovations of new technologies and their repercussions. It can be shown that new techniques were implemented to deal with *scarcity* of production factors, that environmental pollution was caused by these new technologies, which in turn lead to new

inventions and innovations in order to avoid pollution. This process, initiated by individuals, institutions and politics, also created new goods which in turn caused new environmental damage and new reactions, both in terms of business and politics. The creativity of scientists, inventers, economic actors and the effective regulations by politicians, who assumed their *responsibility* for the protection of the public, are the driving forces for this *evolution*. We note that a key to understanding this development is its long *time* frame which leads to the occurrence of *novelty* and *ignorance* that have to be dealt with by individual and collective, economic and political actors over the course of time. The corresponding *time* frame takes us from the middle of the 18th century to the middle of the 21st century, i.e. means we shall deal with a *time* frame of about 300 years.

From potash to synthetic soda

The textile industry is called "the mother of the industry" because it was the first economic activity in history that can be termed an "industry". The most important production factor for bleaching was so-called potash; it was obtained by burning wood. For one ton of potash, for instance, 1400 tons of birch wood had to be burned. This demand quickly led to deforestation. The production factor wood became *absolutely scarce*.

For this reason, potash had to be replaced by natural soda, which, however, had to be imported from Egypt or Spain. In Spain, it was obtained from Barilla, salt tolerant plants that became the primary source for soda ash. When soda from Egypt became *absolutely scarce* and the sea blockade of the British navy stopped the import of Barilla from Spain in the 1760s and 1770s, this led to an increasing *scarcity* of soda on the European continent. Facing this situation of *social ignorance* concerning the substitution of natural sources of soda, the French Academy decided to offer a prize for the invention of the synthetic production of soda in 1775. This can be seen as an intervention by a social institution; thus a collective actor assumed *responsibility* in order to overcome a situation which was not solved by the market. It took 16 years until this prize was awarded to Nicholas Leblanc in 1791. He had *invented* the so called Leblanc process, thus *novelty* occurred.

Only in 1822, i.e. 31 years after its invention, the Leblanc process *was* finally *innovated* in a way that allowed it to be implemented on a large scale in the industry. The *scarcity* of natural soda was overcome by the manufacturing of synthetic soda. This *innovation* was triggered by economic actors behaving according to the *homo oeconomicus* model. This development illustrates the importance of the concepts *scarcity, ignorance, homo politicus, responsibility, economic evolution, novelty* and *homo politicus*, as it will be described in more detail is Section 4 below.

Leblanc process, pollution and Chlorine Alkali Bill

While up to now we took an economic and a social perspective when talking about *scarcity* and the way it was overcome, in a next step we turn to an aspect of production that requires the natural sciences. The solution of the situation of *scarcity* was an economic and social success, but it demanded its price since the production of synthetic soda in the Leblanc process led to the occurrence of *joint products.* The production of 100kg of soda was accompanied by the production of 69 kg hydrogen chloride (HCL), 68 kg of calcium sulphides (CaS) and 83kg of carbon dioxide (CO_2) (see Müller-Fürstenberger 1995:182; Baumgärtner et al. 2006b: 293-299). The first two *joint products*, HCL and CaS created serious social problems and caused damage in the economic system (for details see: ibid.: 294-295). We see that this chemical process necessarily leads not only to unwanted, but also harmful *joint products*. This illustrates the relevance of natural sciences for an appropriate analysis of economic-environmental interactions. We observe how over *time*, the solution of a problem of economic *scarcity* generated a new problem: pollution of air that endangered humans, animals and plants. The consequences of this pollution became more and more of a problem. This led to public social resistance in the beginning of the 1830s. Here, people stood up and assumed their *individual* and finally politicians *their political responsibility.* Again it took a long *time* until politics reacted and passed legislation, the Chlorine Alkali Bill from 1864. This political intervention, an act of *political responsibility*, turns out to be a new element within the process of social, economic and environmental *evolution.*

As a result of the Chlorine Alkali Bill, the industrial producers were obliged to convert hydrogen chloride to hydrochloride acid, which they released into rivers and lakes. So instead of polluting the air, water was used as a receptor of pollutants and was thus subsequently polluted. This resulted in the death of fishes in lakes and rivers and the corroding of economic assets such as metal boats and sluice gates, consequences people were unaware of – a case of *social ignorance*. 10 years later, renewed public resistance as a result of *individual* and *social responsibility* led to the amendment of the Chlorine Alkali Bill in 1874 which regulated the introduction of fluid waste as well. Politicians had finally assumed *their political responsibility.*

Deacon process – a next step in evolution

The pressure exerted by the public, initiated intense research, even before introduction of the legislative amendment of 1874. The result of the research was the *invention* of the so-called Deacon Process of 1869. Within the Deacon process, a new type of *novelty* occurs: Its *innovation* has made it possible to convert a bad, hydrochloride acid (HCL), into a highly desirable good – pure chlorine. Again, *social ignorance evolved* into *novelty* and thus into *knowledge*. The British chemist Henry Deacon as well as those economic actors who invested in and *innovated* the new technology acted as *homines oeconomici.* But they were driven not only by economic motives, but also by the demand of the public for solutions to the pollution problem. Individuals and social groups maintained the high

pressure over a long period of time, and their success on a legislative level shows that they were driven by *social responsibility* and *power of judgment.* Hence, these individuals and social groups acted as *homines politici.* Pure chlorine, produced thanks to the Deacon process, was a good in such high demand that its production became more important. So ultimately, chlorine turned into the main product and soda the by-product.

At first glance, it seems as if the problem of resource *scarcity* had not only been overcome, but a bad (HCL) had even been transformed into a very valuable good. Thus, challenges led to economic progress: An undesired and poisonous *joint product* led to socio-political and legal demand for change, which in turn led to strong incentives to overcome a technological and environmental status quo. In short, technical progress was able to overcome a severe economic and environmental problem and at the same time contribute to economic welfare through the production of pure chlorine.

We conclude that the emergence of *resource scarcity* and pollutants as a result of *joint products* can be seen as a trigger for *inventions* and *innovations*. *Ignorance* concerning technical progress in terms of *novelty* had positive and negative effects. While the positive effects were a result of creativity in the market, negative effects could not be solved by the market, but only by politics.

CFCs: the destruction of the ozone layer

The solution for the pollution by hydrogen chlorine (HCL) appeared to be a story of success for almost a century. One major aspect of it was the development of chlorofluorocarbons (CFCs). Shortly after the invention of the Deacon Process in 1869, CFCs were created experimentally around 1870. CFCs had many favorable characteristics: They were not poisonous, they were nonflammable and could be used for very different purposes, in particular for heat isolators and cooling. Therefore, they became an indispensable part of everyday life. Mass production of CFCs started from the 1930s onwards. In 1974, 700,000 tons of CFCs were produced and 350,000 tons were emitted from refrigerators, freezers, cold storage facilities and refrigerator-transportation units and as propellants in spray cans.

In 1985, however, it was discovered that the CFCs rise into the stratosphere (12 to 35 km over the earth's surface) and damage or even destroy the ozone layer. This discovery of the amount of destruction came as a complete surprise to scientists and a shock (*ignorance)* to the public and politicians.

The shock was even greater since it was forecasted that it would take until 2050 for the ozone layer to restore itself to the concentration levels of 1970. The proposed necessary reduction of the CFCs in the course of about 65 years was achieved by a worldwide international agreement, the so called Montreal Protocol of 1989. The time span between the *invention* of the CFCs and the elimination of their damaging effects expands over almost two centuries. Once again, *political responsibility*, this time on a global scale, was needed in order to deal with negative effects caused by polluting *joint products*.

The phenomenon of the CFCs makes evident the long-term *time* frame which has to be taken into account in this case. *Ignorance* and *joint production* are challenges that require joint action by creative actors: *homo oeconomicus*, scientists and actors with a long-run mindset and a sense of political *responsibility* and *power of judgment* such as *homo politicus*.

4. Lessons about the temporal structure of economic environmental interactions, ignorance, scope and actors of the problems and their solutions

In the last section we have illustrated how the concepts explained in Section 2 above help us to theoretically grasp, systematically investigate and understand an empirical example from the field of complex nature-economy interactions as well as political reactions in reality. We have attempted to explain how

- the terms and concepts introduced in Section 2 capture the emergence and *temporal* structure of economic and environmental interactions,
- their *short-term* solutions,
- the *ignorance* related to them and the repetition of this sequence when further problems arise from these solutions in the *long run*,
- n this process, *economic* as well as *social* and *political actors* are involved.
- These actors can be connected with the various triggers for the economic, social environmental and political *evolution* we have encountered in our historical example.

For ease of representation, it may be useful to describe this evolution, highlighting not only the corresponding concepts but also the relevant actors, in five consecutive stages:

1. The *scarcity* of production factor wood leads to substitution efforts (1750-1822, from potash to imported natural soda and Barilla). Here, an economic problem is solved by economic actors via the market system.

2. Renewed *scarcity* of soda leads to *inventions* and *innovations*. The question how to deal with absolute scarcity of soda in 1775 led to the announcement of a prize for an *invention* of synthetic soda by the French Academy. The Leblanc process was *invented* in 1791 but not *innovated* until 1822, thus leading to a substitution of imported natural soda and Barilla by synthetic soda.

Here an economic problem was solved by economic and scientific actors via a social institution (*homo politicus*), providing the necessary incentives to promote the *invention*

made available by science and leading to its subsequent *innovation* via the market by *homo oeconomicus.*

3. However, there existed *social ignorance* concerning the environmental consequences of the Leblanc process. In the course of time, social resistance by *homines politici* arose against the effect of the pollution of the HCL caused by consequences of *joint products* of the Leblanc process. They affected people's health and led to a political reaction which initiated a change in the production process over the course of time (1864, Chlorine Alkali Bill).

4. There existed social *ignorance* concerning the environmental consequences of the Chlorine Alkali Bill. Social resistance by *homines politici* arose against the effect of the pollution caused by *joint products* in the water which affected people's health and economic activities. A call for action articulated by society and jointly by consumers (*homines politici*) and producers (*homines oeconominici*) led to the *invention* of the Deacon Process in 1869 and to the amendment of the Chlorine Alkali Bill in 1874. The *innovation* of the Deacon Process caused a very important *novelty*: A polluting substance, HCL, became the basis for a completely new and very valuable product, pure chlorine.

5. In the 1970s, CFCs were *invented*. In 1930, this *invention* was *innovated*, enabling the mass production of CFCs. Again, there was *social ignorance* concerning the health effects of the use of the CFCs, for their potential health dangers were only recognized in 1974 and the causal relationship between damage to the ozone layer and skin cancer was not discovered until 1985 . This came as a great *surprise*, not only to the public but also to science. Due to the great danger, a ban on CFCs was agreed on internationally in the Montreal Protocol. It was predicted that this ban would lead to the reduction of CFC levels in the atmosphere, restoring the levels of 1970 by 2050.

This problem was first discovered and articulated by scientists and physicians. Their demand for a solution as well as demands by social actors (*homines politici*) led to an international political regulation and the substitution of CFCs.

In four of these five cases, it is not the market (and therefore not *homo oeconomicus*) that provides the impetus for change, but social and political forces (and thus *homo politicus*) that set incentives for *evolution* in the form of legal regulations. Individuals act collectively (the protesters) and politics ultimately assume *responsibility* for regulating and changing an economic process with negative joint products.

This call for politicians to assume *responsibility* and enact appropriate regulations is also a well-known phenomenon in the current debate on the environment. In the following, we want to use our concepts to show what needs to be known about the problem and who can and should take *responsibility* for action in general.

5. Approaching the ethical core of the environmental problem

The complexity of environmental problems results from the fact that they are multi-layered. At its core, it is an ethical problem, but the natural sciences and the economy hold essential restrictions for any solutions. We consider the concept of *responsibility* to be an operational approach to come to grips with this ethical problem in practice.

In the context of environmental problems, the concept of *responsibility*, though often mentioned, is not often applied in public in an unambiguous manner.

Three central questions are:

- Who is *responsible* for the causation of environmental problems?
- Who is *responsible* for taking appropriate measures in the future?
- Who are the addressees for these two questions?

Our search for answers to these questions has been inspired by the seminal work *The Imperative of* Responsibility. *In Search of an Ethics for the Technological Age* by Hans Jonas. He turned to the concept of *responsibility* because he realized how challenging the various problems of the technological age were for classical ethical approaches (Jonas 1979: 222). The ability of humans to influence and damage the natural foundation of life was unknown in the context of traditional ethics in earlier times. Nature was considered to be outside the realm of human action. Jonas' approach is to reformulate the classical term of *responsibility* in the context of environmental destruction. He developed an "imperative of *responsibility*" that basically augments the obligation of humans to preserve the natural environment as it is the foundation of human existence (see Jonas 1979: 36; Baumgärtner et al. 2006b: 226; Becker et al. 2015). The root of this obligation lies in the power given to human beings by technology and the potentially destructive dynamics generated by it. Jonas formulates in the first two sentences of his preface of the German edition:

"When Prometheus was finally unleashed and given unprecedented force by science and relentless momentum by the economy, this called for an ethic by which he voluntarily restrains his power to prevent calamity to mankind. The transformation of the promise of modern technology into a threat, or its inextricable ties to it, form the starting point of this book." (Jonas 1979:7, our translation).

Jonas sees clearly that freedom and power are linked to *responsibility* since only a person who acts freely can be called responsible for her actions and their consequences (Jonas 1979: 232; Baumgärtner et al. 2006b: 226).

In the following we want to complement the insights of Jonas by making use of the concepts explained in Section 2. We do this by closely connecting the concept of *responsibility* to the concepts of *joint production* and *ignorance*. This helps to understand how environmental problems emerge and how the characteristics of their occurrence shape the way they can be addressed in a *responsible* and sustainable manner.

Once we have developed this understanding, we propose the *homo politicus*, characterized by the ability of *power of judgment* as the actor who practically assumes this *responsibility* (see Baumgärtner et al. 2006b).

5.1 Individual responsibility

First, we ask what *responsibility* means beyond its manifold uses in everyday life. *Responsibility* expresses a causal connection: Whoever is responsible for an act can be ascribed to this act and its consequences. No consequences immediately result from this causal ascription for the actor. Beyond the mere attribution, this "causal power" as Jonas calls it, may have legal consequences and may have moral consequences. An essential precondition for these consequences is the freedom of an individual: "*Responsibility* means that one is the perpetrator of one's deeds. A person can determine his will freely; he is free to determine his aim of acting and to do something in order to realize this aim" (Baumgärtner et al. 2006b: 226). Hence, an individual who acts freely might be held responsible for something legally and morally as well. This means that he can be made "liable" for the action and its consequences on a legal level and has to accept that his actions and its consequences are judged by others as "morally good" or "morally bad" (Jonas 1979: 172; Baumgärtner et al. 2006b: 226f).

What does this mean for the *responsibility* an individual has to assume? This question can be answered by referring to *negative* and *positive responsibility*. In terms of negative *responsibility*, a freely acting individual is obliged to refrain from actions that cause harm to others. Anyone who assumes *negative responsibility* acts in accordance with this obligation.

Those who assume *positive responsibility* extend this obligation to refrain from harmful acts and commit themselves to take care of the good condition of those for whom they declare themselves responsible. *Positive responsibility* does not only mean the omission of harmful actions but also working actively towards a good condition.

Joint production and ignorance as limits of individual responsibility

As noted above, freedom is a necessary condition for *responsibility*. "Responsibility is the flip-side to a human being's freedom to act. A person is only the author and master of his actions insofar as he can assume responsibility for his actions and their consequences. That for which someone assumes responsibility can be ascribed to him […] thus, only he who can assume *responsibility* is actually capable of taking concrete action. This raises the question of the extent of one's *responsibility*" (Baumgärtner et al. 2006b: 229). An individual who is not free cannot assume *responsibility* for his deeds.

A second necessary condition for *responsibility* is the ability to acquire the available *knowledge* in society about the consequences of one's actions. Individual *ignorance* does not necessarily protect an individual against legal punishment. However, whenever this *knowledge* cannot be acquired, *responsibility* cannot be assumed (for a detailed analysis see ibid: 230f). Thus, it may occur that *joint production* is connected with *irreducible ignorance.* In contexts of high complexity, for example in the case of CFCs explained in Sections 3 and 4 above, there was no *knowledge* of the *joint products* or their negative consequences. Individuals as well as society were in a state of *closed ignorance* because no one was aware that possible negative *joint products* existed concerning the use of CFCs. Hence, neither the individuals nor society can be ascribed *moral* or *legal responsibility* (ibid. 229-233).

Hence, the question is: Who assumes *responsibility* in this case? We will turn to the answer in Section 5.4.

5.2 The scope of political responsibility

Returning to Hans Jonas, we find that he gives politics a special position in the area of *responsibility*: He speaks of a duty of power and the associated *responsibility* for something: "Yet there is a completely different concept of responsibility which does not concern the ex-post facto reckoning of what has been done, but rather the determination what is to be done. Accordingly, I therefore do not feel primarily responsible for my behavior or its consequences but instead for the thing which lays claim to my actions." (Jonas 1979:174, our translation).

Where does this new form of *responsibility* come from and how is it justified? Jonas argues that the voluntary will to power and its assumption becomes an obligation.

Political power extends the sphere of influence beyond individual borders and thus also the sphere of *responsibility*. This extended kind of influence is found in the ability to change the legal framework of action and the incentive structures for individuals, economic actors and communities by means of laws and political measures. This influence of politics has been illustrated in the history of the soda chlorine industry by the Chlorine Alkali Act, its amendment and the Montreal Protocol (see Sections 3 and 4).

In contrast to the private individual, politicians have far more access to the available social *knowledge* since they can rely on science, expert committees and specific studies. Hence, they are not restricted to the same extent as individuals. Nevertheless, politicians are confronted with *irreducible ignorance*. Since political *responsibility* assumes *responsibility* for the good state of society, politicians are nevertheless obliged to make good decisions when they are confronted with complexity and *irreducible ignorance* (Baumgärtner et al. 2006b: chapter 14).

5.3 *Power of judgment* as a concept of how to deal with political responsibility

How should politicians live up to this *responsibility*? First of all, political actors must be aware that they are assuming a positive *responsibility* for something (a department, a ministry, a region or a country and its people). This *responsibility* means that they are committed to creating and maintaining the good state of this "something". In order to fulfill this obligation, especially in the context of environmental issues, it is essential to develop an understanding of the complexity, a *knowledge* of the emergence of *absolute and relative scarcity as well as evolution, joint products* and the three forms of *ignorance.*

Taking on *political responsibility* then means acting in the face of these difficulties and being able to make, while not best, good decisions. Since politicians are confronted with different contexts, i.e. every problem they face is different from the one they faced before, they cannot rely on general rules but have to find a new solution for every context. To be able to develop these solutions, they have to rely on the faculty of *power of judgment. Power of judgment* understood as *knowing how:* Judgment knows how to deal with concepts such as the ones mentioned above and how to apply them to specific contexts and cases (see Klauer et al. 2017: 107).

5.4 The homo politicus as an actor of political responsibility

Unlike the *homo oeconomicus, the homo politicus* is not exclusively interested in its own welfare but in the good condition of the whole, the political community (a department, a ministry, a region or a country), and the common good.

"*Homo politicus* looks for solutions that are firstly objectively measured and secondly find a consensus in the long term, i.e. the de facto agreement of the actors and interests involved and affected. In pursuit of this goal, *homo politicus* will not sacrifice its own welfare but will nevertheless put its own interests - including those in the gain of personal power - in the back seat if necessary.

But in order to achieve this goal - the agreement of actors with often quite different interests - *homo politicus* must be able to understand these interests or the perspectives of the respective interested actors. This ability is the prerequisite for *homo politicus* to be able to judge, decide and act in such a way as to meet the approval of these actors who are affected by the decision and action of *homo politicus*" (Faber, Petersen, Schiller 2002, our translation).

"In the power of judgment and the action of *homo politicus* determined by it, we therefore have an element of unpredictability. Because this action can change both laws and

institutional framework conditions of the economy as well as norms and preferences, it represents a possible source of *evolutionary* change" (ibid, our translation) and hence an element of *irreducible ignorance*.

To be able to do this, the *homo politicus* has to find means to achieve his aim and make sure that it is realized. This requires the willingness and courage to do what is recognized as right and to take on personal risks and disadvantages (ibid.).

6. Outlook

We owe the essential line of our argumentation in this paper to decades of interdisciplinary research at Heidelberg University.[5] In our scientific work[6], we repeatedly had the experience that it is not so crucial to simply accumulate *knowledge*. Rather, we found it to be important to systematically structure the available *knowledge* by assigning it to more general concepts. For example, economic activity can be described by the concept of *joint production* and its repercussions on the environment; the behavior of actors can be categorized by the concepts of *homo oeconomicus* and *homo politicus*. Temporal developments can be described by our concept of *evolution*, Neo-Austrian capital theory (Faber 1979, Stephan 1995), Faber, Proops, Speck (1999) and a theory of stocks (Faber, Frank, Klauer, Manstetten, Schiller, Wissel 2005; Klauer et al. 2017, Parts II to IV).

We also found that concepts like *joint production* and *responsibility* allow us to gain essential insight into the physical, economic and the ethical side of production, since they have a structural relatedness (Baumgärtner et al. 2006b: 223-267).

With this in mind, we have directed our attention once again to the development of such structural relatedness; in this way we have generated new concepts and methods (see e.g. Faber, Manstetten, and Proops 1998). Our overriding question has been: How does the economy interact with nature and vice versa? This question can be refined and applied as a theoretical perspective to environmental policy areas such as waste, water, CO_2 and biodiversity.[7]

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[5] This research has been published in printed media such as books and journals. Additionally, a summarized and systemized version of this material has been published as a website: www.nature-economy.de
Furthermore, a discussion paper reflecting on the process, methodology and content of this website has been published by Faber, Petersen, Frick and Zahrnt (2018).

[6] This endeavour was motivated by our advising activities for national and international governmental bodies on environmental policy over the course of four decades. These activities have accompanied our scientific research from 1980 to the present. This engagement has made us aware of scientific gaps.

[7] See for waste: Faber, Stephan, Michaelis (1989); for water: Faber, Niemes, Stephan, (1983); Jöst et al. (2006); Niemes and Schirmer (2010); for CO_2 and climate change: Proops

Asking these questions is one way of developing a perspective and approaching the respective fields and concrete cases. It is certainly not the only way. The concrete examples of waste, water, CO2 and biodiversity and the corresponding scientific literature show how many other approaches there are, because each of these areas demands the recognition of its context and the different questions asked. And yet we believe that our conceptual approach with a systematic order of *knowledge* and the elaboration of relatedness between the individual concepts and areas of *knowledge* represents a perspective of its own. In practical terms, "practical in the sense of practical philosophy which concerns itself with human action, this means that these fields can only be understood through science which is accessed through simpler overarching concepts. These concepts do not form a hierarchically structured system within our approach. Instead they are conceived as a network of interdependent concepts that reference each other but also remain categorically distinct from one another" (Faber et al. 2018: 6).

We argue that the systematization of the necessary existing *knowledge* is an important success factor for environmental policy. This line of argument is reinforced by current digital developments, for an incredible amount of *knowledge* is readily available in a few clicks. Paradoxically, however, people do not perceive this *knowledge* as a reduction in complexity but as an ever growing overload.[8]

In this paper, we have employed six general concepts to analyze environmental problems, to reduce complexity, and to offer theoretical and practical considerations to approach them. In addition to the six concepts in this paper, our approach includes nine others (Faber et al 2018). Of course, many more such general concepts exist, like *resilience*[9], *flexibility*, *freedom*, *will*[10] and *consent* which we consider promising.

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[8] See Faber, Manstetten (2010: 6-8.)

[9] See for example: Derissen, Quaas and Baumgärtner (2011), Baumgärtner and Strunz (2014), Ruth (2018): 78f.

[10] Petersen (1996); Petersen, Faber (2001).

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