Evolution

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Abstract

Darwin's seminal book on biological evolution has triggered an ongoing debate on evolution, in biology and in general. Not until the 1960s did Mainstream Economics start to take up Joseph Schumpeter's ideas of evolutionary thought for economic analysis in one of its branches, Evolutionary Economics. However, Mainstream Economics did not emphasise the relevance of his ideas for environmental problems. Ecological Economics, on the other hand, uses the concept of evolution as a key to diagnose, analyse and treat environmental and resource problems.

We show the fruitfulness of the concept of evolution by examining predictable and unpredictable processes, inventions and innovations, 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.

Our example of the soda-chlorine industry shows an evolutionary process in an economy over the course of 250 years. First, new technologies and products are invented due to resource scarcity. Second, increasing pollution caused by the new technology is recognized, and third, environmental legislation is implemented, leading to new inventions, and so on. Hence new questions lead to new answers in an evolutionary way.

Related Concepts: IGNORANCE, BASICS OF TIME, JOINT PRODUCTION, POWER OF JUDGEMENT, IRREVERSIBILITY, TELEOLOGICAL CONCEPT OF NATURE

1. History

Looking at the history of evolution in economics, it is expedient to differentiate between two strands: a branch of Mainstream Economics called Evolutionary Economics and an aspect of Ecological Economics. We first turn to Evolutionary Economics within Mainstream Economics. Joseph A. Schumpeter (1883-1950), one of the great figures in economics of the 20th century, is viewed as the founder of Evolutionary Economics. His book *Theorie der wirtschaftlichen Entwicklung* (English translation: Theory of Economic Development) (1912) is considered the starting point. However, Karl Marx's (1818 – 1883) ideas heavily influenced Schumpeter.

Evolutionary Economics

It took over half a century until Evolutionary Economics slowly became recognized and began flourishing as a branch of Economics in the nineteen-eighties [Marshall (1890), Veblen (1902), Alchian (1950), Penrose (1952), Cyert and March (1963), Hirshleifer (1977), Schelling (1978). Boulding (1981), Nelson and Winter (1982), Mathews (1984), Norgaard (1984), Witt (1980, 1987) and Clark and Juma (1987)].

Evolutionary Economics uses evolutionary ideas drawn from biology. While it primarily analyses technical change, it also examines the emergence of institutions and, more recently, preferences Presently, Evolutionary Economics has established itself as a small but articulate field within the discipline of Economics (see e.g. Witt, 1993 and Nelson, 1995). This achievement was brought about by conceptual, theoretical and applied work which in turn has influenced other branches of Economics, such as Game Theory, Industrial Economics and Public Choice.

Ecological Economic approach

Our Ecological Economics approach (Faber and Proops in collaboration with Manstetten 1998; see also Faber and Manstetten 2003/2010: chapter 10) differs from Evolutionary Economics both in terms of methodology and) content. With regard to the former, we rely more on biological concepts. With regard to the latter, we consider biology as well as physics to be of central importance alongside economics when it comes to Ecological Economics. We therefore develop a concept of evolution which is applicable to all three sciences at the same time.

Thus, our approach is intrinsically interdisciplinary, again in contrast to Evolutionary Economics and Mainstream Economics. With regard to content, our emphasis is on the interaction between economic activity and the environment in the long-run, an issue which is not given the prominence it deserves in Mainstream Economics. In particular, we analyse the relationship between natural resource scarcities and inventions, the effects of the corresponding innovations on the environment and inventions which are created in reaction to environmental pollution and resource scarcity. This allows us to examine the relationship between the possibilities of predictability and the occurrence of novelty, and it gives us a framework for empirical analysis in the long-run. It also makes us aware of the limits of our knowledge and thus emphasizes the importance of the precautionary principle.

Neo-Austrian capital theory

Finally, we note that our approach has been influenced by our work on Neo-Austrian Capital Theory, (Bernholz 1971, Faber 1979, Reiß 1981, Stephan, 1995 Faber, Proops and Speck in collaboration with Jöst 1999; Winkler 2003, Faber and Proops 2004; Faber and Winkler 2006) in the tradition of Austrian Capital Theory, Schumpeter being one of its main representatives. Thus our approach shares with Evolutionary Economics an emphasis on technical change, but in contrast to it our approach is embedded in the relationships between the economy and the environment.

In addition, the Neo-Austrian approach differs from Mainstream Economics by focussing on the temporal structure of consumption and production, a focus which is of particular importance for Ecological Economics, for much damage to the environment can only be observed in the long term.

2. Theory

In Section 2.1 we define and discuss our definition of evolution, then in Sections 2.2 and 2.3 we present evolution in biology and physics.

2.1 A general concept of evolution

Our starting point

When approaching Ecological Economics, we begin with the need for a concept of evolution which is broad enough to encompass evolutionary processes in physical, biological and economic systems (Faber and Proops in collaboration with Manstetten

1990/1998: 17 ff.). We therefore found it useful to start with a very broad notion of evolution which emphasizes *change* and *time* [see Faber, Proops 1998: chapters 2 and 3; see also BASICS OF TIME].

“It is known that the objects of study in biology at any point in time are the result of an evolutionary process. We shall try to show that this is also true for other sciences, in particular for economics and even physics.

We develop a general framework for conceptualising evolution. We proceed in such a manner that biology, physics and economics can be contained within the framework. In this way we also intend to contribute to the development of interdisciplinary research between these three disciplines. For example, physics, biology and economics are of vital importance for environmental analysis, in which physical, biological and economic systems evolve simultaneously, interacting with each other.

Evolution is a very encompassing concept, and it is used in many different contexts. For example, one speaks of physical, biological, social, political and economic evolution. Key concepts for a definition of evolution in biology are mutation, heredity and selection, while in systems theory one employs the concepts of self-evolution, self-sustained development, and self-reference. For our conceptual framework it was useful to begin with the boldest possible starting point, for otherwise there was the danger that evolution would be seen in too narrow a sense. Such narrow conceptualization risks the exclusion of important key aspects of evolutionary processes.

In our view, the key characteristics of evolution are (1) change, and (2) time; we consider them also to suffice as elements for the following starting point:

Evolution is the process of something changing over time.

In a strict sense this is not a definition, but a tautology. It simply gives information as to how we use the word ‘evolution’. We do this intentionally so as not to exclude any processes from our consideration. This approach is in line with Heidegger’s insight (1927/1979) that fundamental notions can only be explained in a circular way. Complementary to this approach is Wittgenstein’s method (1922/1969). He would have qualified our definition as ‘nonsense’. Instead he would have asked how one could use the notions of evolution in different contexts. It is precisely in this spirit of Wittgenstein that, throughout this and the next sections, we seek to illustrate the concept of evolution in biology, physics and economics, rather than seeking a definition of the concept of evolution in a close analytical way. [BASICS OF TIME, where we deal extensively with Aristotle’s concept of time, for which change, and motion play an essential role].

Our aim was to specify and operationalize this conceptualization of evolution. To develop our conceptual framework, we used concepts originally formulated in biology. In particular, we used the notions of genotypic and phenotypic evolution. In our generalization, by 'genotype' we mean the 'potentialities' of a system, and by 'phenotype' we mean the 'realization' of these potentialities. In this sense our concepts are not *derived* from biology; rather they had their first expression, as a special case, in the biological literature. Thus, when we use the terms genotype and phenotype, we are *not* making analogies with biology. We are, rather, extending the usage of these terms in what we feel is a natural manner.

It will turn out that the evolutionary process, as we understand it, *always* takes place, albeit at different velocities. The evolution of our present physical laws and fundamental constants took place a long time ago and within a very short time period; the biological evolution of species lasts millions or thousands of years and proceeds continually; the evolution of social and economic institutions takes place in hundreds of years, decades, or even shorter periods" (Faber, Proops 1998: 19-21).

Predictability, novelty and ignorance

These three concepts are related to each other. Since we shall deal with them extensively in the concept IGNORANCE, we shall confine ourselves here to a short explanation of them [POWER OF JUDGEMENT]. First, we turn to predictability. There exist predictable and unpredictable processes in time. "Before discussing these processes, it is appropriate to note that actual processes lie on a continuum with regard to their predictability. That is to say, certain processes are predictable with greater certitude, while others are entirely unpredictable, many processes fall into neither of these of these categories because we are ignorant of them or of their structures. However, for our purposes it is convenient to employ the rough categories above." (Faber, Proops 1998: 23) To illustrate predictable processes we give four examples:

(1) A ball falling to the pavement.

(2) The dynamics of launching an earth satellite.

(3) An ice cube in a sealed warm room, becoming a puddle of water and then atmospheric moisture. Molecules in water are not predictable in an exact sense.

(4) The life-cycle of an organism (chicken) is generally predictable, but detailed development is impossible" (Faber, Proops 1998: 24).

We conclude from these examples: A predictable process is one whose time path can be described in advance deterministically or stochastically from beginning to end.

While up to now we have discussed processes as observers, we can also include the observer in our analysis. To do so, it is useful to determine the extent to which the observer is in a state of ignorance concerning her behaviour in the processes. “The notion of ignorance is relevant because it reminds us, on the one hand, of the limits of predictability which lie in the human structure of cognition. But on the other hand, there are also limits to predictability which lie in the nature of certain processes themselves. It is to such processes that we now turn” (Faber, Proops 1998: 26).

We now give three examples of unpredictable processes:

(1) The history of the evolution of species: unpredictable.

(2) The modern world result of inventiveness: unpredictable.

(3) Creative activity: artistic endeavours like music, painting, and writing: unpredictable.

In each case the process and its outcome are unpredictable for the observer, hence, she is in a state of ignorance. An unpredictable process results in novelty for the observer, which restricts her area of validity of predictability (Faber, Proops 1998: 26-27).

Equilibrium and evolution

The notion of equilibrium is used in biology, physics, and economics. How does it relate to our notion of evolution? To answer this question, we first turn to a general definition of equilibrium. We speak of “*static equilibrium* when there exists a state, say state A, in a system such that all of its variables remain at the same values indefinitely, as long as there are no exogenous influences.

We say that a system has a dynamic equilibrium when there are a series of successive states available to the system that are repetitive, and where the repetition takes a constant amount of time. For example, the system may be making the transitions State A → State B → State C → State A →, with a constant period of repetition of, say, T units of time. Again, this repetition relies on the absence of exogenous influences.

We see that static equilibrium is a special case of dynamic equilibrium, where all the successive states in the repeating cycle are the same state.

Having defined the concepts of evolution and equilibrium, we can now explore their relationship. The first thing we can say is that a system undergoing evolution need not exhibit an equilibrium. On the other hand, a system which is necessarily always in equilibrium cannot exhibit evolution. Thus, the concepts of evolution and equilibrium do not necessarily rely on each other, except to give each other definitional distinctness. However, many important evolving systems exhibit one or more equilibria, either static and/or dynamic. The concept of equilibrium in evolving systems will be central and will allow us to examine the issue of predictability in evolving systems.

Thus, in physics, equilibria can often be observed directly. For example, a pencil lying on a desk is in static equilibrium, while a freely swinging pendulum is in dynamic equilibrium. In both these cases we need only our visual sense to detect the equilibrium. To establish the existence of equilibrium in a biological system is necessarily much more complicated because the nature of such systems is that they are heterogeneous and multiply connected. Unlike in a simple physical system, for a biological system we need first to conceptualise the nature of equilibrium, and then to detect it through careful measurement and calculation. By the same argument, we see that it is even more difficult to establish the existence of an equilibrium in economics, as the final objects of economics are human beings, thus the level of abstraction of an economic equilibrium is very high" (Faber, Proops 1998: 22-23).

2.2 Evolution in biology: genotypes and phenotypes

"Understanding the long term confronts us squarely with the problem of predictability, ignorance and the emergence of novelty. We draw on concepts from biology to show that precisely the emergence of novelty has been encountered in discussing biological evolution" (Faber, Proops 1998: 43).

Genotypes and phenotypes

We employ the notions of genotype and phenotype from biology which are central for our following analysis. We first define them as they are used in biology.

"An organism has a certain appearance, capabilities, characteristics, etc. The appearance and characteristics that it presents to the world are known as its phenotype. The phenotype displayed by an organism results from the interplay of two factors. The first factor is the potential inherited from its parents; i.e. its genetic make-up, or genotype. The second factor is the environment of the organism; for example, organisms that are otherwise identical (e.g. identical twins) will grow to different sizes and exhibit different capabilities if they are subjected to widely differing nutritional regimes.

It is generally accepted, in biological systems that the genotype affects the phenotype directly, but there is no such direct influence of phenotype on genotype" (Faber, Proops 1998: 28).

“From the above discussion it is clear that the genotype reflects the ‘potentialities’ of the organism. The phenotype represents the ‘realisation’ of these potentialities, in so far as is permitted by the environment of this organism. In all the discussion that follows, we shall be concerned with how the potentialities of biological, physical and economic systems evolve and also how the realisations of these potentialities evolve. As a convenient short-hand, and to reflect our desire to discover a fundamental conceptualisation of evolution, when we refer to ‘potentialities’ we shall use “genotype” and when referring to ‘realisations’ we shall use the term ‘phenotype’).

As mentioned above, we are not transferring the concepts of biology to other sciences but are assuming that the notion of genotype is of a general character and has been particularly successfully applied in biology. We propose to employ the concepts of genotype and phenotype in the analysis of other disciplines. We hope that this application to other fields of study will also reveal why these evolutionary concepts were first, and successful employed in biology.

To clarify the concept of potentiality and genotype, it is helpful to draw on the discussion of novelty in the middle of the preceding section. In terms of novelty, we may say that the potentialities at a certain point in time comprise all possible future events, through the interaction with the environment with the exception of novelty. Hence, a change in the potentialities of the system, i.e. a change in its genotype, is equivalent to the occurrence of novelty” (Faber, Proops 1998: 28- 29) because the corresponding process of this change was unpredictable. Hence, the observer is, during this process, in a state of ignorance and experiences novelty at the end of this unpredictable process.

Definition of ‘organism’, ‘species’ and ‘biological system’

“At this stage it will be useful to clarify what is meant by ’organism’, ‘species’ and ‘biological system’. An *organism* is the basic unit of independent life, whether plant or animal, that contributes to reproduction. A *species* is the set of all organisms whose genotypes are so similar that they allow interbreeding (e.g. horses, dogs, primroses etc.). A *biological system* consists of an interacting set of species, each species being made up of distinct but genetically similar organisms. For example, the flora and fauna which coexist in and on an area of wetland would constitute a biological system.

The phenotype as described above refers to an individual organism. As organisms of their various species interact with each other in large and heterogeneous biological systems, it is useful to consider an overall description of such a biological system. Such a description would be a listing of the phenotypes of all the organisms within the biological system in terms of the species represented and their relative abundances. We term this description *macro-phenotype*.

Similarly, the genetic potential of a biological system of organisms could be listed to give that system's *macro-genotype*. The list comprises all genotypic information of all organisms of the corresponding system and is independent of the relative frequencies of the organisms.

The advantage of descriptions of biological systems in terms of macro-genotype and macro-phenotype is that it gives explicit recognition to the fact that the evolutionary process deals with systems rather than with individual organisms.

There has been a long-running debate in evolutionary biology as to whether the unit of evolution is best conceived as being the individual organism, the species, or the entire heterogeneous system (Levins and Lewontin 1985).

We have noted above the usefulness of describing systems in terms of the macro-genotype and macro-phenotype. It is clear from our discussion that an individual organism can only exhibit phenotypic evolution, not genotypic evolution; this is so, because for the latter at least two successive organisms have to exist in order to exhibit genotypic change. In contrast a species can exhibit not only phenotypic but also genotypic evolution. The genotypic evolution of a species, however, is influenced by that of other species. It is therefore not possible to study the evolution of one species in isolation. For this reason, it is useful to consider the biological system as our unit of evolution" (Faber, Proops 1998: 29-30).

As mentioned above, it is not useful to examine the genotypic evolution of any species in isolation. "Much more useful is to think of the evolution of the entire system; that is to consider the coevolution of many interacting species (Thompson 1982)" (Faber, Proops 1998: 40).

While the developments of phenotypic evolution, e.g. the abundance of species, often take place at rapid rates, the changes to biological genotypes occur extremely slowly. The full scheme of biological evolution is thus seen to be the interplay of extremely slow and unpredictable changes in the macro–genotypes with relatively rapid, predictable changes to macro-phenotypes.

"It is worth noting that the very different rates of phenotypic and genotypic evolution in biological systems allow us to distinguish predictable and unpredictable parts of the whole evolutionary process. (We note that in economic evolutionary processes it is usually much more difficult to separate out the predictable from the unpredictable processes.)" (Faber, Proops 1998: 35-36).

”The time path of a process exhibiting genotypic evolution has no ‘end’. We can expect that genotypic evolution will be a never-ending process. Certainly, there is not a particular final state towards which it tends, unlike the many systems exhibiting predictable equifinal phenotypic evolution” (Faber, Proops 1998: 39).) To give an example: The birth of a chicken and its growth can be predicted if its parents, nutrition and environment are known. The result will be an adult chicken. In our terminology, the process of maturation is equifinal; “we call a process equifinal, if, given certain boundary conditions, the predictable outcome is independent of the initial conditions governing the process. For example, if a small ball is placed anywhere on the inner surface of a large bowl, then under gravity the ball will eventually settle at the unique base of the bowl. We see that the final position of the ball is predictable, and is also independent of the initial position of the ball. It is therefore clear that any equifinal process whose dynamic behaviour is known is predictable, though, of course, not all predictable systems are equifinal. We see that the final position of the ball is predictable” (Faber, Proops 1998: 25).

Coevolution and niches

“The environment can be viewed as a kind of ‘filter’ for the corresponding phenotypes, meaning some environments are favourable for the development of a phenotype, in terms of climate, water, soil etc., and other environmental conditions are not. However, every species, and indeed every organism, is part of the environment of each organism in a biological system” (Faber, Proops 1998: 39).

“From the point of view of any individual organism, or species, only a limited part of the full environment actually interacts with the organism or species. This limited range of interacting environment is known as the species’ ‘niche’. For example, the niche of a honeybee comprises a limited range of vegetation and airspace, while the niche of the fox comprises a relative limited range of land and the flora and the fauna it contains.

In coevolution, the niche of every species is periodically disturbed by a genotypic evolutionary change in other species. Sometimes a niche may be enlarged or enriched leading to a greater abundance of a species.at other times niches may be reduced, or even eliminated, leading to the extinction of species. However it is worth noting that an increase in the complexity of a biological system, through the emergence of new species, will tend to lead to greater number and diversity of niches. This will open up possibilities for further genotypic evolution. This is clear when we recognise that any ne organism that evolves can act, for example, as both a prey (or forage) species for external predation, and a host of parasites. Therefore, the process of macro-genotypic evolution has the potential to sustain itself and may lead to ever increasing complexity and diversity through the continual opening up of new niches” (Faber, Proops 1998: 39-40).

2.3 Evolution in Physics

“We now turn to a discussion of the role of phenotypic and genotypic evolution in physical systems before moving on to an analysis of evolutionary concepts in economics in the next section 2.4. In our discussion on biological evolution, we have stressed that the potentialities of a system, its genotype, interact with the environment to realise these potentialities, in the phenotype. The systems with which physics is mainly concerned have their potentialities defined by their fundamental constants and laws of nature. The realisation of these potentialities is the observed behaviour of that physical system.

We therefore define the genotype for a physical system to be the fundamental constants and laws of nature. We similarly define the phenotype of a physical system to be the realisation of those potentialities; i.e. its observed physical behaviour. As a consequence of this conceptualisation we see that, unlike biological systems, all realised physical systems have the same genotype. That is, different physical phenotypes are not derived from different physical genotypes” (Faber, Proops 1998: 40-41).

Thus, for example, electrical systems and chemical systems are very different; nevertheless, they both are derived from the same set of physical laws and constants.

As we “discussed under the heading of ‘predictable processes’ (above), predictable changes are often exhibited by physical systems. As these changes are in the nature and appearance of the physical world, in their realisation, we term such change *phenotypic evolution*.

To illustrate how the potentialities (the genotype) of the physical world may through interaction with the environment, give rise to a phenotype and phenotype evolution, we present the following example.

A ball held a certain distance above the pavement has potential energy because of its position and because of the laws of nature. If the ball is released the interaction of the ball and the pavement cause it to behave in a certain predictable manner. The system containing the ball and the pavement tends toward a new equilibrium. The underlying genotype of this whole process is the laws of nature. As we know the initial conditions, and as there is no genotypic evolution, we can say that the system exhibits phenotypic evolution.

From the discussion above it should be clear that physical systems, like biological systems, may exhibit phenotypic evolution towards a state of equilibrium. However, unlike different biological systems, physical systems share a unique and unchanging genotype, comprising the physical constants and the laws of nature.

We mentioned above that modern thought suggests that the universe was unpredictable in its first few moments, as the physical constants attained their present values. One could say, therefore, that even physical systems have experienced one period of genotypic evolution, albeit for a vanishingly short length of time. Even if this theory should be found to be false, it is important because it introduces an understanding of time and evolution into physics, instead of the still present myth of 'eternal laws of nature'. One important development of modern physics is the exploration of the theory of chaos. Consideration of chaotic systems shows us that we cannot escape large areas of ignorance which limit our human cognitive capabilities. This ignorance leads us to interpret chaotic structures as being *novel*, in the sense that we are not able to form realistic expectations of them. Here we speak of *chaotic novelty*, to which we turn" (Faber, Proops 1998:41) later.

We learn from this section that there are structural similarities between biology and physics since they both exhibit the same structure of a genotype and a phenotype. The constancy of the physical genotype allows many more predictable phenotypic processes than biology where the genotype changes over the course of time as will be explained in more detail below.

2.4 Applying the concept of evolution to economics

Mainstream Economics neglects not seldom the historical aspects of economic processes, their dynamics and long-term consequences for the environment [HISTORY OF THOUGHT ON NATURE AND ECONOMY]. This holds true both in teaching and research. Consequently, the importance of our natural living conditions is neglected [SUSTAINABILITY & JUSTICE]. We think that a good approach to Ecological Economics has to include evolutionary and historical aspects.

Let us first turn to the understanding of evolution in Mainstream Economics in particular and in scientific discourse and media in general. Evolution in Mainstream Economics implies that things improve over the course of time. For example, if we speak of the evolution of technology, we think of technological progress, and if we speak of the evolution of the economy, as a rule, it is understood as economic growth. When predicting the future of humankind within the framework of Ecological Economics, we regard this interpretation to be misleading. Hence, our definition of evolution developed above is value free.

Several authors have attempted to employ concepts of evolution as a means to contribute to the foundation of Ecological Economics, in terms of its conceptualisation (e.g. Norgaard 1984, 1985, Faber and Proops 1998, van Bergh 2004, Witt 1980, 1987, 199) or to model long-term interactions between the environment and the economy (e.g. Faber, Proops, Speck 1999, Schiller 2002, Buensdorf 2004, Baumgärtner et. alt. 2006).

This enables us to integrate concepts such as the emergence of novelty, and ignorance into a theoretical framework of Ecological Economics. Moreover, the concept of evolution allows us to differentiate between predictable and unpredictable processes.

We now apply our evolutionary concepts to the dynamics of economies, i.e. their temporal change, in particular to the production and development of new techniques. As mentioned above Evolutionary Economics has put its focus on this subject. However, our conceptual approach is the interaction between economic activity and the environment.

We first introduce the concepts of *genotype* and *phenotype* to economic systems. This will be a hard piece of work since we have to introduce definitions and relate them to economic environmental interactions. However, this conceptual framework will allow us to analyse the object of our main interest: the interaction between human inventions, the temporal process of developing new inventions, and the natural world, in particular the use of natural resources and the repercussions of production on environmental pollution.

We shall see that we again encounter the problem of ignorance, even more strongly than in physics and biology. This is the reason why prediction is much more difficult in economics than in the two natural sciences.

Genotype and phenotype in economics

"In economics, as in biology and physics, we can conceptualize economies in terms of potentialities and their realisations. The former we will call economic genotypes, the latter economic phenotypes. Before proceeding, we should point out that in practice often it may not be easy to distinguish between these two categories, for reason to be discussed below" (Faber, Proops 1998: 45).

We first consider economic genotypes. The notion of the genotype in this broad sense has not, up to now, been defined in economics. Unlike biology, there is no obvious evidence for an economic genotype because there are so many avenues to arrive at a definition. Hence there is no obvious way to recognize changes in an economic genotype, i.e. economic mutations.

However, if we consider social activity as a macro-economic phenotype (i.e. the interaction of various social phenomena), we often observe changes that cannot be predicted ex ante. For example, we observe the emergence of new preference orderings, new technologies, as well as new legal, economic and social structures. Such processes of change lead to a complete reorganisation of the macro-phenotype, i.e. social activity.

How can these transformations of the macro-phenotype be understood? To this end we believe it is helpful to suppose a change has occurred in the potentialities of the social system; i. e. a genotypic change. Although the essential genotype of society is not exhibited by this change, and hence cannot be observed directly, we may highlight those elements which are particularly apt to be considered as candidates for social genotypes.

The elements of an economy which we consider to be suitable candidates for the economic genotypes are as follows: (1) Preferences of the economic agents. (2) The economic agents' *view of the world*, including religious and social norms. (3) The technology (i.e. the set of all techniques which are known in that economy). (4) The legal, economic and social institutions.

If we observe changes in any of these four elements we shall speak of genotypic change of the economy. The nature of these elements defines the potentialities of a particular economy, i.e. defines its genotype.

As mentioned above (Section 2.2) the phenotype in biology results from the interplay of the genotype and the natural environment. The same holds for the economic phenotype. It can be conceived of as resulting from the interaction between the economic genotype and those aspects of the (natural) environment relevant to the society, such as the endowment of natural resources and ecological conditions. From this it follows that even if the economic genotype is constant the development of the economic phenotype may alter because of changes in the environment.

The economic phenotype is a realisation of these potentialities. For a market economy it may contain the following elements: (1) The techniques of production employed. (2) The types of capital goods employed, and their quantities. (3) The types of production and consumption goods produced. (4) The quantities of these goods, and their prices. (5) The redistribution of consumption, income and wealth among the economic agents. (6) The market structure.

From the definition above, it is clear that just as in biology we defined the unit of evolution to be the whole interacting biological system, for economics we define the unit of evolution to be the entire set of interacting agents and their institutions and artefacts. We note that over the course of history the size and complexity of economic systems, and thus our unit of economic evolution, has tended to increase. For a self-sufficient hunter-gatherer society, the unit would be the band, i.e. the group of all its members, while at the present time the high level of integration of national economies suggests that the unit of evolution should be regarded as the global economy.

The dynamics of economic phenotype and economic genotype

We suggest that the great bulk of dynamic (i.e. temporal) economic modelling can be regarded in terms of the evolution of economic phenotypes. “For example, comparative international trade theory can be conceptualised as phenotypic evolution. In the classic model, England shifts its production towards cloth, while Portugal shifts its production towards wine. The equilibrium pattern of trade that it is eventually established is mainly dependent upon the structure of production, tastes, resources and techniques available. Pursuing this example further, were there to be a disruption to this equilibrium pattern, and this disruption were then removed, the equilibrium pattern would be re-established in due course.

Considering entire societies, some exhibit very slow change of genotypic change, and hence can be adequately described purely in terms of the phenotype. Hunter-gatherer societies seem to have changed very little over many thousands of years, and peasant agrarian societies also seem to show relatively stable genotypes. This, of course, is in contrast to the rapid rates of genotypic change exhibited by modern industrial societies. From these considerations it follows that the distinction between genotype and phenotype might be useful for the analysis of economic history. Very often the assumption of given constraints to behaviour by economic agents, and a general expectation of optimising by these agents, will give us equilibrium outcomes; i.e. the system will be predictable and equifinal. This tendency in economic analysis is most clearly seen in the struggle by general equilibrium theorists to discover ‘reasonable’ models of economic activity which give rise to unique and stable equilibria in price-quantity space.

In our view, this working through of the dynamics of economic systems, where tastes, techniques and resource availability are taken as fixed, can justifiably be termed economic phenotypic evolution.

Genotypic evolution, by contrast, requires changes in tastes and techniques, as well as in economic institutions. For example, the process of industrialisation over the past two hundred years has been one of continually changing economic institutions, changing production techniques and a continually expanding list of natural resources which have been put to economic use. For instance, discoveries in physics stimulated the engineering development of nuclear power, which rendered uranium an economic resource, whereas previously it had been regarded of only limited usefulness. The development of microelectronics and the corresponding increase in the economic evaluation of germanium (used in transistors) is another example of this process of economic genotypic evolution.

Just as in the biological illustration above, economic genotypic evolution cannot involve the notion of an equilibrium outcome. Unlike the case of biological evolution, however, economic genotypic evolution may take place very rapidly, as is particularly evident in the evolution of the microelectronics industry. Indeed, the rate of change in the genotypic specification (the technical capabilities) in this industry is so rapid that successive changes in specification occur before a new phenotypic equilibrium can be established. The very notion of an equilibrium in such rapidly evolving industries seems to us therefore of limited usefulness, since the complexity of the phenotypic response to such rapid genotypic evolution is considerable (as illustrated in Fig. 3.1 of Faber, Proops 1998: 49)" (Faber, Proops 1998: 47-48).

We have recognised that we find the same fundamental structure in economics as in biology and physics. However, while the genotype in physics developed in microseconds and has remained constant, the phenotype in biology changes slowly and the genotype in the economy changes very fast. These differences imply important consequences concerning the predictability in physics, biology and economics. We turn to them in detail in Section 2.6. below.

2.5 The interaction between invention, innovation and the natural environment

For Ecological Economics, the interaction between invention, innovation and the natural environment is of particular relevance because ecological economists cannot restrict themselves to a narrow concept of economic welfare but have to use the economy and the environment as a reference framework. To introduce the concepts mentioned in the title of this section, "we first need to define some terms.

The *technology* of an economy at any moment in time is the set of techniques which are known, even though not all of them will necessarily will be used.

Invention is the addition of a novel technique, which expands the technology.

Innovation is the process of introducing a technique of the technology which has not been used up to now.

While invention occurs at some point in time (or during a relatively short time period), it takes time to innovate a new technique because the introduction of a new technique makes it necessary to construct and establish the corresponding necessary capital goods, as well as to train the workers. It is obvious that this innovation gives rise to many adjustment processes over time throughout the economy, including the process of diffusion.

Using the notion of phenotypic and genotypic evolution, we can characterise the process of innovation as economic phenotypic evolution, and the generation of invention as genotypic evolution.

We have seen that genotypic evolution is a prerequisite for phenotypic evolution in biological systems. The same statement holds correspondingly for economic evolution: Economic genotypic evolution is a prerequisite for economic phenotypic evolution. The phenotypic nature of the economic system offers further potentialities for genotypic evolution. In the case of biological systems, the potentialities lie in niche exploitation, as discussed above. In an economic system, niche destruction, in the sense of the long-term depletion of natural resources, is an important motivation for seeking an improvement in economic technical potentialities; i.e. in seeking economic genotypic change. This genotypic change leads, in turn, to niche production through the use of new natural resources.

We illustrate the interplay between phenotypic and genotypic evolution as follows. Consider a resource-using economy which, through the working of its market systems, has established a predictable equilibrium; i.e. the relative prices and relative quantities produced are stable and overall output is growing at a predictable rate. This would be equivalent to the phenotypic equilibrium of an ecosystem, as discussed above in Section 2.2. If the resources used are steadily be depleted by economic activity, then this will initially cause marginal adjustments in relative prices and quantities, and a reduction in the overall rate of growth.

This Phenotypic evolution can be compared with the phenotypic evolution of an ecosystem subject to, say, a slight but continuing alteration in climate over a long period, such as the general warming in northern latitudes after the last ice age. However, long-term depletion of resources by an economy is likely to initiate a search for new and unpredictable techniques of production which use less of the diminishing resource (resource-saving invention) or make use of alternative resources (resource-substituting invention). The new techniques give rise to a new and unpredictable genotypic description for the economy system; the new economic genotype in turn produces a new phenotype which must now, through market operations (phenotypic evolution), establish a new, predictable equilibrium in the economic structure.

While we have restricted our considerations to the production side, we could widen them by taking into account the inventions and innovations of economic, social and political institutions" (Faber, Proops 1998: 49-51).

2.6 Comparing biology, physics, and economics

In this section we seek to show how economics differs from physics and biology in its conceptual structure and concerns, as dictated by the relative speeds of phenotypic and genotypic evolution that occur in the three disciplines. This perspective is of importance for the interdisciplinarity of Ecological Economics because only in this way it is possible to obtain an encompassing view of the problems of economic environmental interactions. This kind of broad perspective does not exist in Mainstream Economics, which has led to the neglect of many environmental problems.

Biology

In biology, the interaction between there genotypic evolution and phenotypic evolution is much richer. The biological genotype is contained in its phenotype. Equilibrium in a biological population is maintained because "the genotype and phenotype are recursively maintaining each other through the productive process.'…. Darwinian evolution occurs when mutation initiated by a random effect creates a new genotype 'which in turn produces a corresponding new phenotype. If the latter passes through the filter of the environment, natural selection, then a new genotype will establish itself besides the old one. Otherwise only the old genotype will continue to exist. Supposing the mutation is successful, then this will generate a change in the abundance species, therefore constituting a period of phenotypic evolution and we can speak of genotypic evolution" (Faber, Proops 1998: 52-53).

Physics

The relationship between the genotype and phenotype is straightforward in physics: Its "complete genotypic evolution developed under less than a second at the beginning of the universe (Hawking 1988). Thereafter, there was no more genotypic evolution, but only phenotypic evolution. Hence, genotypic evolution no longer takes place, i.e. there is no emergence of novelty of potentialities. In our terminology, physics deals only with phenotypic phenomena. Therefore, there is no recursion between genotypic and genotypic evolution in physics, which is in contrast to biology and economics.

The stability of the potentialities of physical systems has allowed physics to deal only with predictable processes, enabling physicists and mathematicians to seek and to find numerous simple and elaborated methods of dynamics. This ability to concentrate on problems which have predictable dynamics (albeit of chaotic and other nature), is, we believe, the major source of the enormous success physics has enjoyed over the past three centuries. There is little scope for the emergence of novelty, and there is little (extreme) ignorance, and no genotypic change" (Faber, Proops 1998: 52).

Economics

We remind the reader that we defined in Section 2.4 above the concepts of a macro-genotype and macro-phenotype in economics. "That is, they embody the full potentialities of the whole economy and the full realisations of those potentialities by the economy. Here the economy can be described as exhibiting normal economic activity. For ease of illustration it may be supposed that the economy is in a stationary state, i.e. business as usual. The potentialities of the economy (i.e. knowledge base such as preferences, technology, legal and economic institutions) are being realized in productive economic activity, and this production in turn allows the maintenance of the knowledge base. Therefore, as in the biological case, the genotype and phenotype are in a recursive, self-maintaining relationship. For an economy, the genotype is not localised in a genetic structure, as for an organism. Also, the genotype of an economy has a rather autonomous existence, at least for societies which can record information. This is an important distinction between biological and economic systems with regard to their evolution" (Faber, Proops 1998: 54).

A change of the genotype of the economy occurs, for example, when an invention happens; "the market conditions will act as a filter for whether this invention will be realized. However, unlike the biological case, the increase in the potentialities of the system is often retained. Here we recall that this can be the case because we are referring to the macro-genotype and the macro-phenotype. So, the realisations of an economy may not alter, even though the potentialities do alter. It may be possible for a new invention to be retained in the knowledge base but not affect the rest of the economy" (Faber, Proops 1998: 54-55). However, it is possible that this invention is taken up in a later period and successfully innovated, as is the case with the Leblanc Process (see Section 3.1 below). A further complexity relative to biological evolution is that a change in the genotype is not only available to an individual organism in which it occurred, but also different economic actors may employ it.

"The above discussion has shown one major reason why economics is conceptually more complex than biology. A second reason has been mentioned already in in Section 2.2 where we noted that successful genotypic changes in biology occur relatively infrequently. Biological genotypic evolution can be regarded as movements between successive phenotypic equilibria. For economies, on the other hand, it is obvious that in modern times scientific and technological knowledge has been increasing rapidly and at an accelerating rate. This has led to a tremendous amount of economic genotypic change which takes place at a rate comparable to market adjustments (phenotypic change)" (Faber, Proops 1998: 55-56).

Therefore, economic genotypic evolution cannot be regarded as movements between successive phenotypic equilibria. Hence, one often does not know within economic considerations what the essential driving factors are. Metaphorically speaking, we do not know what ship we are sailing on.

"We now offer a third reason for why economics is conceptually more difficult than biology. As we pointed out above, the phenotype cannot affect the genotype in biology. In contrast to this, in economies the phenotype not only maintains the genotype (its potentialities, i.e. the knowledge base), it also generates it through research and development activities. That is, the phenotype does affect the genotype in economies.

In summary, while we see great similarities between the evolutionary processes exhibited in the biological world and in economies, we consider economies to be conceptually more difficult than biology for the following three reasons: (1) In economies, *unsuccessful* additions to the genotype can be preserved. (2) In economies, genotypic evolution often takes place at a similar rate to, and sometimes even faster than, phenotypic evolution. (3) In economies, the phenotype can affect the genotype" (Faber, Proops 1998: 54-55).

2.7 What is the value added by our evolutionary approach?

The problem of depletion of natural resources, the substitution of resources by inventions and their subsequent innovation, the pollution and destruction of the environment by economic activity can only be examined over the long term. In contrast to Ecological Economics, the standard approach by Mainstream Economics has no adequately conceptual framework available for this task. The reason is that understanding the long term confronts us squarely with the problem of predictability, ignorance and the emergence of novelty, which are not in the focus of Mainstream Economics [BASICS OF TIME; IGNORANCE].

By drawing on concepts from biology, we show how precisely the emergence of novelty has been encountered in discussing biological evolution. Moreover, by employing concepts from physics, we can identify the extent to which we can and cannot predict developments in the long term. This enables us to become aware of our ignorance and to incorporate this knowledge explicitly into our theorising and environmental policies. Putting the focus of our attention on our ignorance and not on our knowledge is a decisive change in economic theory and environmental policy. A case study of this evolutionary approach is given in chapter 3 below, illustrating the various concepts.

3. Practice

3.1 An evolutionary-ecological case study of the chemical industry

Using a case study from the soda and chlorine industry in the 19th century, we want to illustrate why the evolutionary perspective is fruitful to describe and analyse long-term interactions between the economy and the environment from an ecological-economics point of view. It exemplifies the close relationship between the increasing scarcity of resources, the repercussions of the extraction and exploitation of resources on the environment, and the importance of ignorance and novelty [BASICS OF TIME; IGNORANCE; JOINT PRODUCTION; HOMO OECONOMICUS & HOMO POLITICUS]. It also shows that long-term optimisation does not exist in reality, yet due to the occurrence of novelty, there exists, at most, myopic (i.e. short-sighted) optimisation.

In addition to our conceptual framework of evolution, in this chapter we draw on insights developed in JOINT PRODUCTION, in which we have extensively examined and analysed the relationship between thermodynamics, joint production and pollution (see Baumgärtner et. alt 2006: Chapter 16).

3.2 On the use of natural factors of production in the textile industry

One important contribution of the 18th century British textile industry was potash, which was produced by burning significant quantities of wood. Deforestation led to serious scarcity of this renewable resource and resulted in the substitution of potash by soda. As well as being used for the bleaching of textiles, soda was also employed in the production of soap and glass. Soda at that time could be produced in France and Britain from several natural resources, the most important being seaweed and imported Spanish barilla. French soda manufacturing was seriously hampered when the import of barrilla by maritime trade was cut off by a British sea blockade in the second half of the 18th century. People were as a loss as how these supply shortages could be overcome. This circumstance led the French Academy to announce that a prize would be awarded for the invention of an industrial production process for soda. In 1792 the prize was awarded to Nicolas Leblanc for his invention of synthetic soda manufacturing from rock-salt (halite), sulphuric acid, lime and coal. This novelty had not been predicted and changed the genotype of the economy. The use of this novelty spread rapidly to other countries undergoing industrialisation at the time and changed the phenotype – a circumstance which was predictable because of the profitability of this technological invention.

Pollution due to joint products of soda production and the Chlorine Alkali Bill

Soda, however, was not the sole output of the Leblanc production process; there were also environmentally damaging by-products, especially hydrogen chloride. The chemical was released into the air and caused damage to the people living near the factories and neighbouring agriculture. That circumstance could actually have been predicted but was not noted at first. It took over four decades until the resistance against such emissions in Great Britain lead to the 1864 enactment of the Chlorine Alkali Bill. This bill demanded that the hydrogen chloride be dissolved in water, thereby stopping its emission though chimneys. As a result, the hydrogen chloride, which was now in the form of hydrochloric acid, was released into rivers. Since the hydrochloric acid corroded the hulls of boats and flood gates, and endangered the fish stock, the Chlorine Alkali Bill was amended in 1874 such that this way of disposal could not be continued.

Up to the innovation of the Leblanc process, only the interaction between scarcity and substitution of resources and the invention of new technologies affected economic development. However, with the invention of the Leblanc process, environmental issues also needed to be given consideration.

People were ignorant as to how this situation could be changed. The next stage was the invention of the so-called Deacon process by Henry Deacon (1822-1876) in 1868, which was again a novelty. This made it possible to extract pure chlorine from hydrochloric acid. Since elementary chlorine could in turn be sold, this is an illustration of another novelty, namely turning an unwanted by-product into a wanted one. A further novelty was the tremendous demand for chlorine, which led chlorine to become the main product and the original main product, soda, became the minor product. This was an unpredicted development. The invention of the Deacon process was completely unforeseeable ex ante and, hence, unpredictable in principle, which may well serve as a further example of an evolutionary development of this economic system.

The chlorine industry

While our focus up to now was on the production side, it shifts to the consumption side in the last stage of this case study. Putting chlorine on the market starting in the last quarter of the 19th century merely moved the environmental problems linked to chlorine from the production sphere into the consumption sphere. A century later, during the last quarter of the 20th century, it became evident that the disposal of goods containing chlorine causes serious environmental problems. This discovery was a novelty since society had been completely unaware of this circumstance. Some observers go as far as to say that the chlorine industry, which amounts to 60% of the turn-over of chemical industry in Germany, has been one of the great failures of the industrial development of the 20th century.

We want to illustrate this statement with one product of the chlorine industry, chlorofluorocarbons (CFCs). They were experimentally produced around 1870. They have very good qualities as they are not toxic, not flammable and can be used in very different applications, in particular in refrigerators and heat isolators. They became a central part of our living conditions and welfare. In 1974, 700 000 tonnes were not only produced, but 350 000 tonnes were also emitted into the atmosphere from old refrigerators, heat isolators etc. Society at large was ignorant of the repercussions of releasing these emissions into the atmosphere. By chance, in 1974 it was discovered that the CFC molecules went up into the stratosphere (12 to 55 km above surface level) where they destroyed the ozone layer (35 km above surface level). While computer simulations projected the damage to be minor, the discovery of dramatic damage in 1985 came as a great surprise. Again, we are faced with novelty. It was agreed in the international Montreal Treaty that the production of CFCs had to be successively reduced by 2002. However, the CFCs were expected to be emitted until 2010 such that their concentration would increase until 2012. Only in 2050 can we expect the concentration to be reduced to the same level as in 1970.

The history of the CFCs encompasses a time span of almost two centuries. In contrast to hydrogen chloride, one could not smell or feel the CFCs. Their stock accumulated in the atmosphere over long periods of time. Their damage to the ozone layer could only be discovered by scientists with great time lags. The market participants were ignorant of the consequences of their behaviour for over a century. Again, a solution could not be achieved through national politics, but only internationally.

4. Literature

The content of MINE originates from scientific work published in books and peer-reviewed journals. Quotes are indicated by a special typographic style.

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The main source of this concept is the following publication:

Faber, M. and J.L.R. Proops in cooperation with Reiner Manstetten (1998) Evolution, Time, Production and the Environment (3rd edition) Springer Verlag, Heidelberg.

4.1 Recommended literature

Key literature

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