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# Bioeconomics as economics from a Darwinian perspective

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**Synopsis:** Bioeconomics—the merging of views from biology and economics—on the one hand invites the 'export' of situational logic and sophisticated optimization developed in economics into biology. On the other hand, human economic activity and its evolution, not least over the past few centuries, may be considered an instance for fruitfully applying ideas from evolutionary biology and Darwinian theory. The latter perspective is taken in the present paper. Three different aspects are discussed in detail. First, the Darwinian revolution provides an example of a paradigm shift which contrasts most significantly with the 'subjectivist revolution' that took place at about the same time in economics. Since many of the features of the paradigmatic change that were introduced into the sciences by Darwinism may be desirable for economics as well, the question is explored whether the Darwinian revolution can be a model for introducing a new paradigm in economic theory. Second, the success of Darwinism and its view of evolution have induced economists who are interested in an evolutionary approach in economics to borrow, more or less extensively, concepts and tools from Darwinian theory. Particularly prominent are constructions based on analogies to the theory of natural selection. Because several objections to such analogy constructions can be raised, generalization rather than analogy is advocated here as a research strategy. This means to search for abstract features which all evolutionary theories have in common. Third, the question of what a Darwinian world view might mean for assessing long term economic evolution is discussed. Such a view, it is argued, can provide a point of departure for reinterpreting the hedonistic approach to economic change and development. On the basis of such an interpretation bioeconomics may not only go beyond the optimization-cum-equilibrium paradigm currently prevailing in economics. It may also mean adding substantial qualifications to the subjectivism the neoclassical economists, at the turn of the century, were proud to establish in the course of their scientific revolution.

**Key words:** Darwinian world view, evolution, evolutionary economics, development, subjectivism, natural selection, analogy, adaptation, evolutionary progress, preferences, genetic endowment, growth of consumption

**JEL Classification:** A12, B00, D11, O10

## Introduction

Bioeconomics—the newly emerging research paradigm combining two independent, though in many respects related, scientific disciplines—can be given a two-way interpretation. In the one interpretation it appears as a vehicle for 'exporting' the situational logic and the sophisticated optimization concepts developed in economics into biology. Maximization under constraints is not an unknown concept in biology (see, e.g., Maynard Smith 1969). As a result of 'nature's parsimony', as David Ricardo once put it, humans, but no less all other species, have to adapt to the scarce means available for keeping up their life function and for maintaining and perhaps expanding their niche. Yet, optimality is often only implicitly

dealt with in biological research (see Ghiselin 1992) and new insights may therefore be gained by approaching selected biological phenomena with an economist's attitude.[1] The other interpretation focuses on a reverse transfer of ideas. Human economic activity has changed in an accelerating fashion over the past few centuries and seems likely to continue to do so. In order to explain this persistent change much of the static theorizing in economics, directed at explaining (or better rationalizing) why certain kinds of behavior and institutions can be observed in the economy at a certain point of time, may be argued not to fit well. Analytical tools and concepts developed in biology, particularly in the Darwinian theory of evolution, for making sense of evolutionary change may therefore be of interest to economists who want to broaden their intellectual tool box.

This second way of transporting ideas within a bioeconomic research program is pursued in the present paper. Attempts in this direction have often been undertaken, reaching as far back as, e.g., Schäffle (1877/78), Marshall (1898), Veblen (1898), Reinheimer (1913). In more recent times the notion plays an important role in evolutionary economics (see Hodgson 1993 for a survey). To provide a systematic assessment of the relevance of Darwinian thought to economic theorizing, three different aspects will be singled out and treated in turn in the present paper. In the second section, Darwinism-as-a-scientific-program is considered. In view of the fact that, in neoclassical economics, Newtonian ideals seem to be dominant it will be discussed whether the change that Darwin's research program induced in the sciences on a paradigmatic level could, and should, be taken as a model for changing paradigms in economics. The third section turns to the relevance of Darwinism-as-*the*-theory-of-evolution. If the economy evolves—which can hardly be denied—can concepts and tools from the Darwinian theory be utilized, by way of analogy or on a metaphorical level, for making sense of economic evolution? As will be argued, objections may be raised against a too uncritical transfer of ideas so that an attempt at generalizing over common features of different domains of evolution may be a better strategy than constructing misleading analogies. The forth section deals with the broader aspect of Darwinism-as-a-*Weltanschauung*, i.e., as an overarching paradigm for interpreting the long-run development of the human economy. Many sociobiologists believe that human behavior is not exempt from Darwin's theory. In which sense can this conjecture be substantiated, and what are the economic implications? The final section offers some conclusions.

**Darwinism as a model for changing paradigms?**

The history of science has it that the succession of research programs dominating the work in a scientific discipline rarely is a matter of smooth transition but rather one of revolutionary change. A scientific revolution of this kind took place almost simultaneously in two different disciplines in the second half of the last century—the renowned and fundamental 'Darwinian revolution' in natural history and the sciences in general and, less widely acknowledged than that, the 'subjectivist (or marginalist) revolution' in economics. This coincidence is a true irony of history as the intentions pursued in those two revolutions could not have been more opposite.

Darwin's (1859) grand theory of the evolution of life on earth and the descent of the species by means of natural selection amounted to nothing less a challenge to the then

dominant Newtonian world view. In the naturalists' descriptive and classificatory endeavors—a crucial input in the Darwinian revolution, (see Bowler 1989, chapters 5–7)—an enormous morphological and geographical variety of species had been recorded which rendered the idea of simple deterministic laws governing the world rather implausible. How could the interpretation of evolution in nature as a process of the continuous creation of new, not previously existing, species be reconciled with the notion of the cosmos as an unchanging, pre-existing, gravitating system? From the latter point of view, everything, including all species, had already been established by the original act of creation in the Genesis. In contrast, Darwin's interpretation of the speciation process, and his theory of common descent, suggested that species developed from their predecessors under the adaptive forces of variation and natural selection. In this 'open' evolutionary process possible states of rest could, at best, be considered transitory phenomena.

It is worth noting that, in challenging the Newtonian ideal of the sciences, both Darwin and Herbert Spencer, who also contributed to preparing the revolution, seem to have been influenced by intellectual stimuli from outside biology. These influences emanated from the upper class liberal 'laissez faire' social philosophy of Victorian England which Spencerism and Darwinism, in a sense, transferred to nature (Young 1988, Desmond & Moore 1991, Richards 1992). From Darwin's diary, and the correspondence of both Darwin and Spencer, it is obvious that they knew the work of Adam Smith and Malthus (Bowler 1989, pp. 89–104, 164–175). The latter's 'Essay on the Principle of Population', published in 1798, suggests a systematic relationship between reproductive success and competition for subsistence (or 'struggle for existence') because resources are limited. This relationship seems to have had a crucial impact on Darwin's thinking (see Herbert 1971). The individualism in Adam Smith may have inspired Darwin to posit in his theory an individualistic interpretation of the unit of selection, i.e., the idea that natural selection operates on the differential reproductive success of the single members of the population of a species (Mayr 1991, chapter 6).

Be that as it may, the proponents of the 'subjectivist revolution' in economic theory, Walras (1874/1954), Edgeworth (1881), and Pareto (1896) were, by contrast, eager not only to put a distance between themselves and the classical objective, i.e. labor, theory of value. They also showed an obvious lack of interest in the pre-Victorian (Smith 1759, 1776) and Victorian (Mill 1848) versions of social and moral philosophy. Instead, they were inspired by Jevons' idea of creating a 'mechanics of utility and self-interest' and of adapting economics to the standards of the Newtonian ideal of science. Accordingly, they borrowed their basic concepts from the classical mechanics of gravitating systems which were simplified further to focus only on a state of rest, the (total) market equilibrium, rather than on the actual market processes.[2] Market equilibrium was considered not only as a state where all individual plans were mutually compatible, but also as one in which the utility of all the agents involved reached a maximum, subject to the mutually imposed constraints—the dual formulation of the concept of equilibrium in classical mechanics where the state of rest is associated with minimum free energy (see Georgescu-Roegen 1971, Mirowski 1988).

Carl Menger, the founder of the Austrian school and leader of the subjectivist revolution in the German speaking countries, did not explicitly support a Newtonian ideal for economics as a science, and he obviously appreciated Smith' social philosophy (see Streissler 1994). Yet, as an opponent of the German historical school, he was most explicit in, and gained a

reputation for, rejecting the idea that descriptive and classificatory historical studies could have a major role to play in developing economics as a science (Menger 1884). Thus, he rejected for economics what would have been the equivalent of the contemporaneous endeavors of the naturalists in the sciences. His plea for economics as a 'pure theory' fits well with the underpinnings of the Newtonian ideal and was quite successful compared to the fading influence of the German historical school. From Menger's 'pure theory' a direct line leads to von Mises' (1949) peculiar 'praxeology' and further on to the rigorous apriorism of modern general equilibrium theory.

In view of these remarkably different intellectual developments, and given the overwhelming success of the Darwinian revolution in the life sciences, it may be asked whether, after hundred years, it is time to reverse the retrogressive, Newtonian and anti-historical, tendencies established by the subjectivist revolution. Indeed, there are good reasons for making a shift in economics comparable to the Darwinian revolution. Modern economies are shaken up by incessant innovativeness. Even the most casual empiricism shows ever changing markets, technologies, and institutions. A different question is whether it is possible, and desirable, to make use of concepts and tools developed in the Darwinian approach to evolution or even in biology in general (see Hirshleifer 1977, Khalil 1992) in elaborating an alternative to the prevailing optimization-cum-market-equilibrium paradigm that emerged from the subjectivist revolution. Several writers who contribute to an evolutionary approach to economics do, in fact, favor such a borrowing, whether by way of analogy or even direct transfer. As the next section will show, however, agreement about the desirability of paradigmatic change analogous to a Darwinian revolution does not mean consensus about where this change should lead and how it can be achieved.

**Darwinism as a basis for constructing economic analogies?**

In the light of the tremendous impact which the Darwinian theory of evolution has made, the principles of natural selection and genetic adaptation appear to many to be *the* archetype of evolutionary thought. Evolution is not confined to genetic adaptation in nature. It also occurs in culture in general, and the human languages in particular, and, of course, in the economy. It seems tempting, therefore, to ask whether, and to what extent, the regularities governing evolution in those latter spheres are comparable to, or even identical with, those of genetic evolution. In the evolutionary approach to economics, which developed over the past few decades, more or less loose analogies between genetic and economic evolution are widely appreciated. No wonder, then, that there are a large number of contributions which elaborate on analogy constructions.[3]

However, serious objections may be raised as to whether analogies to natural selection and genetic adaptation are, indeed, a reliable basis for developing the evolutionary approach in economics. Apart from the reservations with respect to the question of which variant of the biological theory of evolution should be taken as the proper reference for constructing economic analogies, specifying, in a convincing manner, how selection works in the economic domain is a major problem. What are the economic entities whose representation over time is supposed to be changed in a systematic way by selection? In the modern, neo-Darwinian synthesis in evolutionary biology, selection operates on the gene pool of a population of

individuals, i.e., a 'species' which (in the case of sexual reproduction) is defined as a group of potentially interbreeding individuals. Roughly speaking, slight differences in the genetic endowments are seen as giving rise to differential reproductive success for the phenotypic carriers of those endowments. Due to the differences in the number of surviving offspring, the composition of the population's gene pool is changed from one generation to the next. The selection 'mechanism' is thus based on a fairly complex interaction between the genetic and the phenotypic sphere. Under the influence of genetic variation through recombination, mutation, genetic drift (particularly in isolated populations), and gene flow (immigration), the selective replication of new variants produces genetic adaptations which make for the emergence and the change of the species.

If economic analogies were to be constructed, an obvious question is thus (as Winter (1975) put it) 'what are the genes?' or, even more basically, what would be the economic analogue to the species? A convincing answer to these questions is lacking. Boulding (1981) explicitly refers to consumer goods such as cars. For Saviotti (1996), products serving certain particular needs provide the analogue. The history of some of these artefacts is well documented and invites a taxonomic systematization comparable to the taxonomic efforts in natural history. Moreover, the historical order in which variants of such artefacts appear can be depicted in a way that resembles phylogenetic trees (see Saviotti 1996). Yet, this seems to be all that can be said to be similar. If there were anything in the domain of artefacts comparable to what is effected by the continuity of the germ plasm in the genetic sphere,[4] it would have to be at the level of ideas and images in the minds of the people who conceive those artefacts and change them. But ideas and images are not only well known for their subjectivity and volatility, they are also created and propagated in a way that seems to follow its own regularities, and these cannot be compared to the regularities governing the genetic mechanisms of recombination and inheritance.

Likewise, the idea that there is something similar to natural selection operating in economic domain is at least controversial (see Ghiselin 1987, Gordon 1988). Economists sometimes talk loosely of markets as selection devices because some businesses or suppliers are driven out of the market by competitive processes. However, in the genetic context, selective forces operating on a given population change the relative frequencies of the genes in a way in which the individual members of the population have little, if any, room to escape these pressures or to deliberately take account of them. In the economic domain, by contrast, the agents are not so helplessly exposed to competitive forces. They may well anticipate developments which entail unfavorable consequences, i.e., selection effects that would be imposed on them from outside ('external' selection). They may deliberately try to change the course of action so as to avoid these consequences. Someone who supplies goods or services may thus respond to tendencies threatening to drive her/him out of the market by changing her/his offer *before* external selection takes place. This amounts to 'internal' selection and is subject to the individual's perceptions of situational factors, expectation formation, the current state of preferences, etc.—that is, all the ingredients of subjective economic decision making that were supposed to be redundant in evolutionary explanations which rely on impersonal selection forces.

If the notion of selection is related to economic institutions rather than to artefacts, the situation is no better. In many contributions to evolutionary economics firms, organizational

procedures, or routines are considered to be the analogues of species. Nelson & Winter (1982), for instance, suggest looking at firms as organizations which have to base their internal interactions on behavioral routines, rules of thumb, and regular interaction patterns. Production planning, calculation, price setting, and even the allocation of R&D funds follow a rule bounded behavior. The authors interpret the corresponding routines as the analogue of genotypes and the firm's specific decisions thus derived are interpreted as the analogue of phenotypes. The latter may be more or less favorable for the firm's overall performance measured in terms of profitable growth. Assuming that routines which successfully contribute to growth are not changed, the actual expansion can be understood as an increase in relative frequency of those 'routine-genes', while routines causing deteriorations in the firm's performance are unlikely to replicate. There is indeed a great diversity of such organizational forms which exist simultaneously. Tracking their history one can see that some of them persist and others disappear. However, this can hardly be taken as evidence supporting the analogy construction because of the role once again played by 'internal' selection in the behavior of organizations. Faced with deterioration firms are most likely to be induced to identify the deficient routines, and to replace or improve them in a kind of intentionally produced mutation of their 'genes'.[5]

For these reasons, reference to something like 'natural selection' in an economic context does not seem more than metaphorical. But, since 'internal selection' has no analogue in the genetic domain, the use of that metaphor may distract attention from a crucial source of economic evolution: human learning, cognition, and creativity. These forms of behavioral adaptation neither follow the same rules as genetic adaptation under natural selection, nor do they necessarily lead to comparable, or even the same, outcomes. At this point it is worth noting that important ideas about how economic phenomena evolve have indeed been derived independently of any inspiration from Darwinism and refer to regularities in the domain of human cognition instead. The most prominent case is Schumpeter (1912) who explicitly rejected the idea of borrowing from Darwinism. As is well known, he emphasized the role of 'innovators' who change the economy by carrying out new combinations, i.e., by launching new products, processes, input markets, and organizational forms of running businesses. Is such a Schumpeterian understanding of economic development entirely incompatible with a Darwinian view? Or can some abstract principles of evolution be identified which are equally valid for both views? Moreover, can such abstract principles be independent of whether evolution is effected by 'external' selection forces as in nature or, to a crucial extent, by 'internal' selection forces as in the economy (or, for that matter, in languages)?

Putting the problem like this means, of course, to raise the level of abstraction. On a most abstract level, evolution may simply be associated with change over time. Evolutionary theorizing therefore has a natural basis in dynamics or, more specifically, in the investigation of transition laws (although many of the implications may be screened even without making the time dimension explicit). Transition laws describe the regularities in the development of a system by determining how the system proceeds from one state to another. If the time dimension is made explicit, transition laws are usually given a formal expression by recursive equations, difference and differential equations, or recursive algorithms.[6] However, a dynamic structure as such is not sufficient to characterize evolution. Conservative systems

in classical mechanics which converge, e.g., to a limit cycle, are dynamic, but certainly far from conveying the idea of evolution. The crucial qualification is that evolutionary change is, in principle, unending (notwithstanding the fact that there may be more or less extended phases of stasis). Therefore, the next question to ask is: where does continual change spring from? In Newtonian mechanics, change is brought about by physical forces which emanate from exogenous sources and intervene in, and displace, a system of gravitating bodies. In the case of living systems (which are, of course, also subject to the influence of external forces) change may be generated endogenously by forces under the command of the system. The economy belongs to the latter type, and economic change may therefore be interpreted as being largely generated 'from within the economy' as Schumpeter (1912, p. 75, my translation) put it.

If evolution is thus defined as the self-transformation of a system over time, how can *self*-transformation be achieved? Availability of free energy, the prerequisite for sustaining life, is obviously a necessary, yet not sufficient, condition. A sufficient condition—and, it may be argued (Witt 1993), a generic feature of evolution—is the capacity of a system to generate and disseminate novelty within its domain. Novelty, indeed, emerges and disseminates in the biosphere, in the economy, or in languages, in different forms of course. In biology, novelty involves the recombination and random mutation of the genes in the gene pool of a population. In linguistics, it involves the invention and popularization of new idioms. In the domain of economics, novelty is, given the discipline's focus on human action, usually interpreted as newly discovered opportunities for acting.[7]

The capacity of a system to create and disseminate novelty causes a diversity of variants or behaviors within the system. Such diversity is partly eroded by competition, and is partly preserved or stabilized by symbiosis (or cooperation). Diversity, and the differences in performance which this usually implies, is a crucial factor in explaining the dissemination processes which, in turn, make up most of what is observable as evolutionary change. An explanation of the particular course of evolution, its current instances, therefore requires good knowledge of the existing diversity, the phenomenological richness of the coexisting and competing forms. In biology this was provided by the empirical and historical descriptions, collections, and studies of the naturalists preceding and accompanying the Darwinian revolution. In economics, to create a similar body of knowledge of instances of economic evolution a comparable systematic interaction between economic historians and evolutionary economists would be desirable. For the present, however, there is only such a dialogue in the debate on technological progress (Landes 1969, Rosenberg 1994, Mokyr 1990).

Besides their taxonomic efforts, the naturalists contributed in yet another way to the paradigmatic shift that took place in the Darwinian revolution. Their records prepared the ground for, and enhanced the understanding of, the role historical contingency, or historicity, plays in the evolutionary process. Once a new genetic variant has occurred, its further success or failure in terms of propagation depends on the current state of its environment. The latter is made up not only of physical conditions, but also of other variants of life which are already present (and which stem from the preceding stages of evolution) and the traits these variants have. These factors exert their influence through what is called the 'occupancy effect'. The effect can be characterized in general terms, but the actual impact on

the evolution of the species cannot be determined without inquiring into the specific historical (and geographical) contingencies. Quite similarly, knowledge about the ever changing institutional, technological, and commercial conditions and their mutual historical contingencies can be expected to be crucial for understanding the actual evolutionary processes in the economy—presumably subject in many respects to something similar to occupancy effects. Both, existing networks of cooperation in the economy and existing competitors have an effect on what kinds of innovative endeavors succeed after they are introduced—this is the equivalent of evolutionary change due to occupancy dependent selection (external to the individual).

As explained elsewhere (Witt 1987), the direction of search for (yet unknown) novelty, and the rate at which this search occurs, also hinge on an occupancy effect. To see this, one has to consider the motivation of the individuals involved in searching for, and trying out, novel ways of acting.[8] Two different, but complementary motives may be conjectured to exist: curiosity and dissatisfaction or fear. As far as curiosity is concerned, people obviously find it entertaining to search for and experience novelty as such—not too much of it, not too little. Thus motivated, novelty is being sought at some basic rate, at all times and in all societies. Yet the economic significance of innovations induced in this way may differ because of social (dis-) approval of certain directions in which novelty may be sought. It is easy to imagine what happens to economic evolution if society discourages search in economically relevant affairs while it tolerates, or even encourages, search for innovations in the arts or, historically quite significant, in warfare technology. As far as dissatisfaction with the status quo, or fear of imagined future courses of events, is concerned, search for novel, not yet known, ways of acting differs from the former case basically in the time patterns and contingencies. It is increasingly likely to be triggered in times of (often anticipated) crises and it tends to fade in times of satisfaction. To a large extent these kind of occupancy effects and other forms of historical contingencies explain why economic evolution is not steady, but is characterized by alternating phases of stasis and of rapid change.

**Darwinism as a *weltanschauung*?**

In a broader view the evolutionary perspective on the ongoing change in the economy raises two deep, interrelated, questions: what are the driving forces and do they imply directional change in economic evolution? In this point, evolutionary processes occurring in different domains may differ. In Darwin's theory the driving force of evolution in the biosphere is adaptation (Bowler 1989, p. 154), itself an outcome of competition between the organisms of a species and between species with all its historically contingent occupancy effects. On a more abstract level it may be considered an interaction between more or less blind variational mechanisms and natural selection. Although Darwin, like almost all of his contemporaries, speculated on evolutionary progress (see Mayr 1991, chapter. 5, Ghiselin 1995), he clearly recognized that there was no final goal served by these mechanisms, as there was no being whose intentions or preferences could be identified with the driving forces of evolution in nature. Socioeconomic evolutionary change, by contrast, involves human creativity and cognition. The driving force of recombinatory search for novelty here is human endeavor, actually a multitude of individual endeavors. Hence

the significance of the motivation—as explained in the previous section: human curiosity and dissatisfaction or fear—for searching for novelty without knowing the outcome. While historically contingent in many complex ways, the multitude of individual motives may, in the grand total, well come down to producing a general direction or tendency in evolution. The same holds for motives and criteria involved in what has been labeled above 'internal selection'. If there is a 'direction' in societal evolution, however, how could it be characterized?

Unfortunately, economic theory has little to offer as an answer to the question. As a result of a rather restrictive interpretation of their domain, economists have traditionally had no great interest in what the arguments in the individuals' utility function actually stand for.[9] With some necessary qualifications, a direct application of Darwinian thought to human behavior is of help here. Since the human decision maker is a result of genetic evolution, her/his behavior, or the preferences underlying it, have emerged from natural selection. This is particularly true of all those preferences conducive to, or instrumental in, enhancing reproductive success. Unless one is prepared to assume that selection pressure on humans[10] is still so strong that it keeps genetic adaptation going, the basic preferences in modern man may be argued to have by and large been genetically fixed in earlier stages of human phylogeny (when selection pressure was indeed strong).[11] These inherited preferences provide the basis on which innate learning, or conditioning, mechanisms operate. Cultural influences are mediated through the latter so that the actual sophistication, subjectivity, and diversity of the full set of individual preferences emerges (see Witt 1991). Because of the survival value they once had, the basic, innate, preferences are likely to be fairly common among humans—with the usual population variance—perhaps, even among many species. These few, weak commonalities may suffice to produce a bias or tendency in the grand total of all subjectively motivated and diverse choices carried out over time and, thus, a corresponding bias in evolutionary change.

In order to add substance to this conjecture, it is useful to briefly review some elementary features of long term economic evolution which may qualify as an expression of such a bias or tendency. An almost trivial fact is the undiminished exponential growth of the human population. A prerequisite for the economic subsistence of a growing population is the provision of labor for the production of the means by which the people can be fed. A remarkable change that occurred only in the last four centuries is that growing technological knowledge made two things simultaneously feasible: a large scale substitution of human physical work by non-human energy sources *and* an increasing volume of production. Wind and water power, wood, coal, oil, natural gas, uranium were tapped one after another (see Marchetti 1980). Human physical energy input successively lost its character as a constraint on the growth of economic production (Weissmahr 1993). This is an important fact for understanding how the economy could develop into its present form, since a dissipative system like the human economy can increase its production only by increasing energy throughput. The way in which energy and materials are combined in the economic production process is contingent on the state of technological knowledge applied. Each technology used implies a certain upper bound on the feasible energy and materials. These bounds can be shifted through switching to more advanced technological knowledge, provided this can be made available.[12]

Without both improved human knowledge and the feasibility of non-human energy flows, the characteristics of modern economic growth—the ever increasing (i) specialization of individual economic activity, (ii) division of labor, and (iii) growth of the scale and scope of the market—would not have been possible. The tapping of non-human energy sources and their substitution for human physical work resulted in an increasingly strong energy flow utilized in production per hour worked, i.e., in increasing energy intensity. The price of energy per unit, measured, e.g., in megajoules (MJ), fell strongly relative to the wage rate. Furthermore, large scale mechanizing the transformation of materials increased output produced per hour worked, i.e., the general productivity of labor. Since, however, energy intensity grew faster than labor productivity, the energy input per unit of output, the 'energy coefficient', increased[13] to a level where current production and consumption now rely on the depletion of the finite fossil energy sources. Similarly, mechanizing the transformation of materials—itself a consequence of the increasing feasibility of non-human energy consumption—not only saved labor in terms of hours worked per unit of output. It also meant a large scale increase of output in terms of physical quantities, i.e., in the flows of materials processed in production. The data for the U.S. show that this was accompanied by an increase in the materials coefficient, i.e., materials per unit of output (Wright 1990). Very many of the flows are made up of depletable materials. The flows go partly to the production process and partly to final consumption. In all cases, the materials are finally transformed into waste, the lion's share of which is dumped.

The background to these developments is the strongly improved 'terms of trade' between human labor and nature's products (non-human energy flows and, with the necessary accumulation of machinery, materials). By 'exploiting' nature in this way, modern economies have been able to shift the bulk of their expenditures, or, to look at it the other way round, the bulk of their income creation, first from agriculture to the industrial sector and then to the service industries. Nowadays, the agricultural and industrial sectors together generate less than half of the domestic income in all OECD countries. Because of the comparatively high input share of human work hours needed in producing services, these services have become continuously more expensive relative to agricultural and manufactured goods.

On the demand side of the economy, the most striking feature of economic evolution over the past few centuries has been the strong growth of consumption both in absolute and per capita terms. This has been accompanied by increasing differentiation of consumer goods and the generation of entirely new groups of products in both the developing and the developed countries. Economists have long known that the demand for certain product groups, such as groceries, does not expand at the same rate as income available for consumption does. However, the phenomenon behind this tendency, satiation, is not theoretically well understood. Because of satiation tendencies, economic growth is no longer only a matter of capital accumulation, technological progress, and productivity increases. It is at least as much a story of how, and what, to sell in the consumers' markets. Qualitative change in the array of final consumption goods, increasing mobility, internationalization of trade in formerly local specialities, and the soaring diversification of the service sector are salient features of this evolutionary process. Despite all efforts to differentiate their products some industries cannot avoid the increasing satiation of the consumers' demands. For other product groups, such as housing space and, in particular, those products which directly or

indirectly provide comfort, safety, health improvements, mobility, and entertainment, the demand effects are exactly the opposite, i.e., for them satiation is still a long way off. The latter products are, of course, precisely those provided by the economy's service sector. Indeed, the fact that, unlike the demand for agricultural and manufactured goods, the demand for (relatively labor intensive and, hence, increasingly relatively expensive) services seems to be nowhere near satiation may be the most important part of the explanation of the growth of the service sector's share in GNP just mentioned.

What do these historical findings tell us? Some of the features of the development do seem to hint to a directional bias or a tendency in long term economic evolution which, as conjectured above, may be attributed to some basic innate preferences. In many respects, humans behave much like organisms of any other species in their attempts to dominate their environment (although those other species have not been able to enjoy long periods of reproductive affluence because they lack man's superior problem solving ability). Humans increase their population size and pay little attention to the ecological dangers that a rapidly growing population means. They make efforts to enhance individual health and life expectancy. They subdue all rival species or drive them to extinction. They use their growing knowledge to find ways of tapping non-human energy sources and thus avoid the burden of physical work. As far as they can, they expand their consumption of items like food, which are directly conducive to survival success, to satiation level. Before satiation is reached, suppliers of those items search for and create more sophisticated ways of consuming those items. However, the satiation features of those items, together with the increasing terms of trade associated with obtaining nature's products, set narrow limits to the expansion of the per capita consumption of those items.

Further growth of income and per capita consumption therefore shift increasingly to less satiable or non-satiable items. The preferences for some of those, like living space, status, (health) care, mobility, entertainment, may again be argued to be part of the genetic inheritance (Witt 1991). For other items in this group, preferences may be the result of cultural influences and individual learning processes. As mentioned previously, from a Darwinian perspective fading selection pressure (or a state of reproductive affluence) always creates room for idiosyncratic behavior which contributes little or nothing to survival. Some of the culturally determined consumption patterns may fit in here, particularly those which are significant for the remarkable problem shift in the most developed countries. That is the shift from providing the means for subsistence for a growing population to avoiding market satiation by switching to the production of (labor intensive) services for less satiable or non-satiable wants. The service sector's share in GNP is therefore likely to continue to grow, unless the depletion of energy and/or materials and/or environmental degradation through waste dumping causes a strong reversal of the terms of trade between human labor and nature's products.

A Darwinian view of economic evolution thus seems to suggest some interesting hypotheses. The focus on common, genetically determined, elements in human preferences which may cause systematic effects in economic evolution is still utilitarian in character, but necessarily reverses some of the radical subjectivist connotations of the 'subjectivist revolution' in economics (Corning 1996). The view suggested clearly contrasts with the anthropocentric standard question of whether the process of economic growth reflects an

increase in subjective utility or welfare for (most of) the agents involved. In fact, the distinction between the inherited parts of the individuals' preferences on the one hand, and the culturally determined, and potentially idiosyncratic, learned parts on the other, may raise doubts as to whether a subjectivist interpretation of hedonism is useful at all. A better understanding of the interactions between genetic endowment and culturally conditioned learning on the basis of a Darwinian world view may well provide criteria for assessing, in a more objective way, the needs economic evolution serves, and why (and in which sense) this should be desirable.

## Conclusions

If bioeconomics—as economics from a Darwinian perspective—is to develop into a fruitful research program, a crucial element would have to be a convincing notion of evolution. At present, a coherent and detailed notion seems to exist only in the principles governing evolution in nature as stated by the (neo-) Darwinian theory. The human economic decision maker him-/herself is, of course, a result of that evolution, and even the extraordinarily extended, modern industrial economy is still embedded in nature. It should therefore be possible to derive from this basis adequately modified concepts which explicate what economic evolution and evolution in nature have in common and where they differ in a significant way. Indeed, this is the premise of the present paper which investigates three different ways in which Darwinism may be considered as a source of inspiration for bioeconomics.

First, the Darwinian revolution provides an example of a paradigm shift which contrasts most significantly with the 'subjectivist revolution' that took place at about the same time in economics. As has been argued, many of the features of the paradigmatic change that were introduced into the sciences by Darwinism would be desirable for economics as well—hence the question of whether the Darwinian revolution can be a model for introducing a new paradigm in economic theory. Second, the fruitfulness and overwhelming success of Darwinism and its view of evolution have induced economists who are interested in making a paradigmatic shift towards an evolutionary approach in economics to borrow, more or less extensively, concepts and tools from Darwinian theory. Particularly prominent are constructions based on analogies to the theory of natural selection. Because several objections to such analogy constructions can be raised, a different way of laying some foundations for an evolutionary approach has been suggested here. As discussed in more detail, this is to generalize, i.e., to identify, those abstract features which all evolutionary theories have in common.

Third, the question of what a Darwinian world view might mean for assessing long term economic evolution has been explored. In these, perhaps most speculative, reflections it was concluded that Darwinian thought can indeed be made fruitful, but only by using rather indirect argumentation. The reason is that the core element, the theory of natural selection, is only indirectly relevant to economic behavior in modern economies. Nonetheless, a Darwinian world view may provide an interesting point of departure for interpreting the hedonistic core of economic theory in a new, non-subjectivist, way. Adopting such a view in evolutionary economics may thus not only contrast with the optimization-cum-equilibrium paradigm currently prevailing in economics. It may also mean adding substantial qualifications to the

subjectivism the neoclassical economists proudly established in the course of the scientific revolution they brought about at the end of last century.

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## Notes

1. In fact, such a perspective is taken in other contributions in this issue.
2. It was not until the advent of the formal treatment in tatonnement models and non-tatonnement models in the 1950s that the 'Newtonian' dynamics of the theory of general market equilibrium were actually explored, (see Negishi 1962 for a survey).
3. See Boulding (1981), Nelson & Winter (1982), Hirshleifer (1982), Matthews (1984), Metcalfe (1989), Faber & Proops (1998), Saviotti & Metcalfe (1991), Andersen (1994), Gowdy (1994, chapter 5), to mention just a sample.
4. In neo-Darwinian theory, the continuity of the germ plasm—Weismann's doctrine—is considered an important condition for natural selection to generate systematic effects (see Kauffman 1995, chapter 1).
5. Nelson & Winter (1982) argue that such improvement or replacement activities are themselves subject to routines, namely those of a higher order, and that the differential growth argument therefore applies here as well. Indeed, it may well be that firms activate higher problem solving routines on a regular basis when running into a crisis or when expecting to do so. Yet, the outcome of these problem solving routines is often more likely to depend on whose constructive and creative talents are involved in pursuing those routines, i.e., on the individual conditions of the particular case, than on the routines themselves. Therefore, differential success in actually solving the problems does not necessarily correspond to differences in the problem solving routines triggered. Different people involved in the same routines may mean different developments. Subjective and situational factors crop up again and determine the decisions actually produced within the routines.
6. This has far-reaching implications for the evolutionary approach on the algorithmic level. Instead of the optimization calculus which corresponds to the neoclassical dogma of rationalizing each and every economic phenomenon, the algorithmic basis of evolutionary economics are transition laws which may, but by no means have to, refer to some optimality criterion. Good examples for different tools used in analyzing transition laws are the simple Markoff chain model by Winter (1971), the logistic diffusion model by Foster (1992), the replicator-dynamics model by Metcalfe (1994), the generalized Polya-urn schemes by Arthur et al. (1987), the master-equation approach by Weidlich & Braun (1993), or evolution algorithms (Schwefel 1992) and genetic algorithms (Birchenhall et al. 1997).
7. Novelty generation as a core element of evolution is a methodologically intricate issue in all evolutionary theorizing. Presumably, the way in which novelty is generated is similar in all domains, namely, some sort of a directed or undirected recombination of already existing elements which creates a variant which was not there before. By this very fact, the concrete meaning and implications of novelty cannot be positively anticipated. This implies a natural constraint on the prediction possibilities. Nonetheless, it may be possible to exclude certain outcomes or courses of action from occurring whatever novelty eventually turns up—a testable hypothesis (Hayek 1964).
8. Note that the epistemological problem mentioned in the previous footnote prevents predicting the *outcome* of creative human problem-solving, but not explanation of what *causes* people to use their creativity when they might otherwise have proceeded along established lines.
9. A notable exception is some recent work in the framework of evolutionary game theory (Hansson & Stuart 1990, Güth & Yaari 1992) which follows the lead of sociobiology in explaining the emergence of 'reciprocal altruism' (Trivers 1971).

10. A vast array of inherited traits determines the potential behavior of each individual in a population of genetically reproducing organisms of a given species. Genetic variety in the gene pool of the population translates into a distribution of traits and thus into variety of potential behavior. The case in which differences in the inherited traits of the organisms imply differential reproductive success and induce a change in the distribution of traits in the gene pool of the next generation is a situation of selection pressure. If selection pressure is significantly weakened or even absent—in a situation of reproductive affluence—behavior which contributes to genetic fitness is no longer selected for. Behavioral variety may then increase, not least due to the inevitable mutation pressure, and include non-adaptive or even maladaptive variants.
11. In a state of reproductive affluence, the Darwinian approach to explaining behavior by reference to its contribution to inclusive fitness is much less significant than under conditions of selection pressure (see Ghiselin 1995). Given the abundance which modern economies have been able to create, it seems evident that human behavior can vary significantly without having a differential impact on reproductive success. In particular, economically more or less efficient forms of behavior do not seem to correlate with generating more or fewer offspring (or with doing so more or less fast), not even when a trade-off between quality and quantity in raising offspring is accounted for.
12. In most cases, technological knowledge has to be translated into technical devices and machinery which require the accumulation of capital in the first place. The capacity to accumulate on a large scale basis seems to be distinctive of *homo sapiens* (see Gordon 1988), presumably because it presupposes a level of intelligence and knowledge allowing for insight and intentionality.
13. The agricultural sector, where a direct comparison between 'primitive' methods of cultivation based exclusively on human energy inputs and modern methods based on non-human energy inputs is possible, provides a striking example (see Pimentel & Pimentel 1996, Tables 10.3, 10.4, & 10.7). The productivity increases in agriculture thus achieved were instrumental in feeding a growing number of people and, in addition, improved the nutrition of the existing population and resulted in an increase in life expectancy (see Fogel 1986).

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